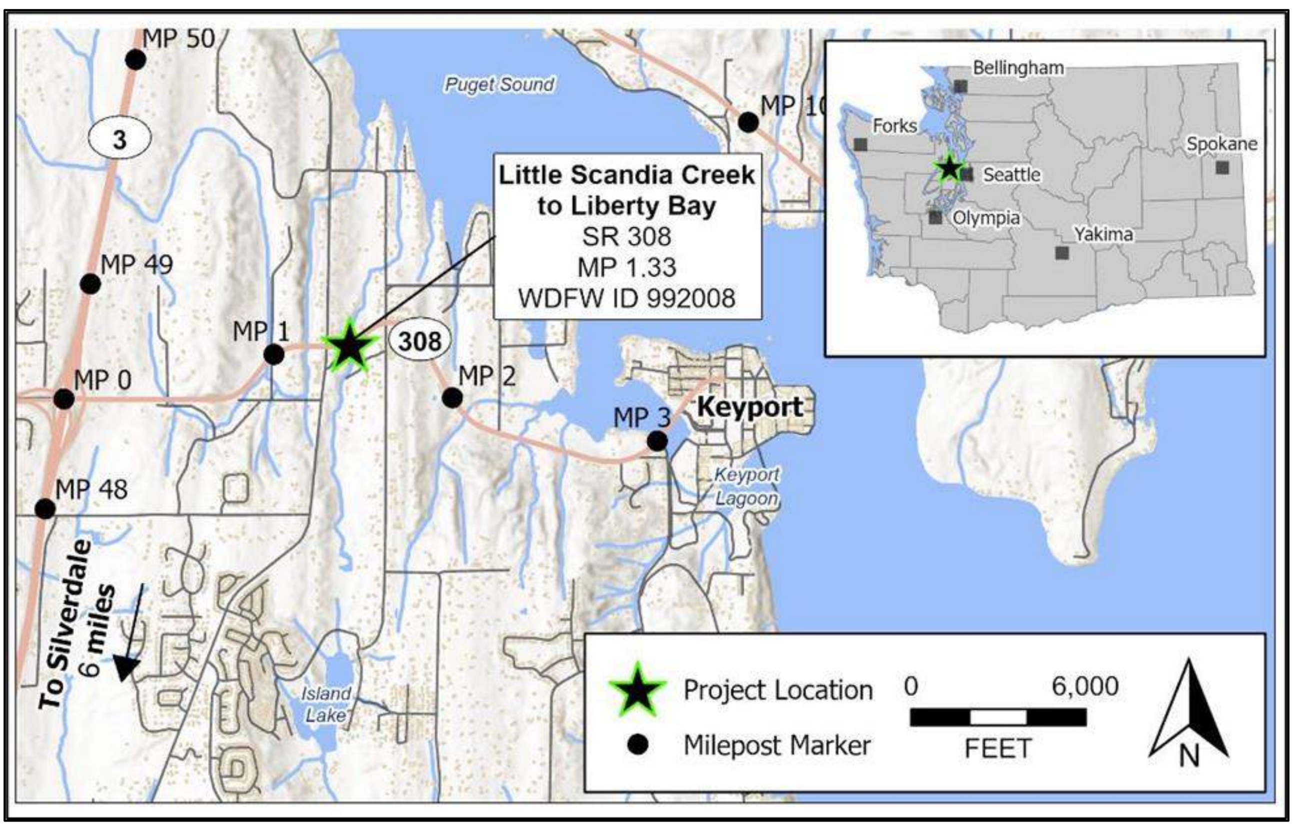
WSDOT Hydraulics Section	Medium Complexity Stream Summary	Date: 3/8/2023
	Project Name: SR 308 MP 1.33 Little Scandia Creek	WDFW ID Number: 992008
	Project Office: WSDOT HQ Hydraulics Office – Olympic Region	County: Kitsap
	Stream Name: Little Scandia Creek	State Route/MP: SR 308 MP 1.33

Brief Project Summary

The Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the State Route (SR) 308 crossing of Little Scandia Creek at milepost (MP) 1.33 within WSDOT's Olympic region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier [ID] 992008) and has an estimated 3,694 linear feet (LF) of habitat gain.

Little Scandia Creek exhibits a meandering pool-riffle planform and has a bankfull width of 10 feet as identified during Site Visit 3 (see attached field notes).

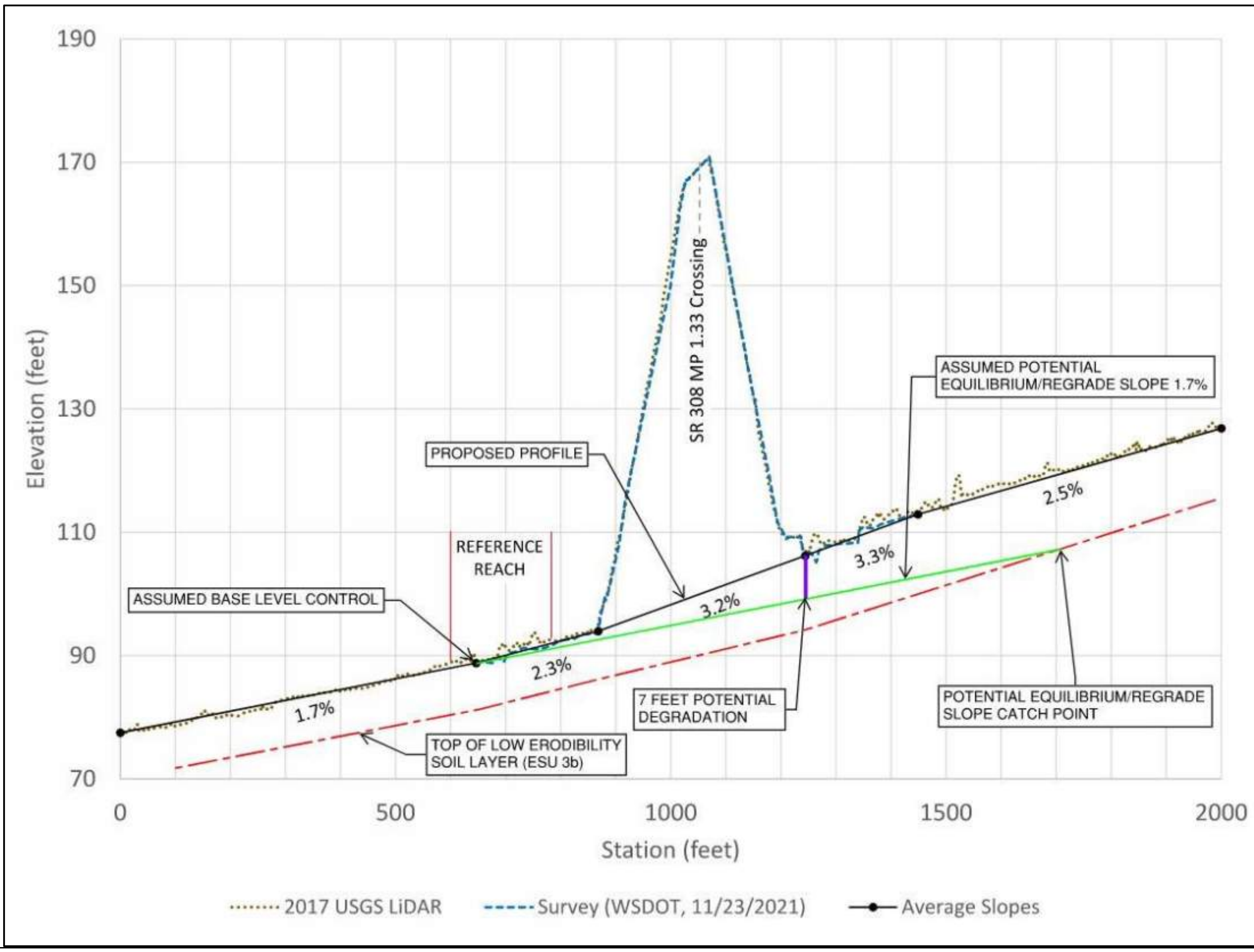
The proposed project will replace the existing 313.6-foot-long, 3.5-foot-diameter round corrugated metal pipe culvert with a structure designed to accommodate a minimum hydraulic width of 19 feet. The proposed structure will be approximately 296 feet long, and the project is proposed to include approximately 450 feet of channel grading (including the structure length). The proposed structure is designed to meet the requirements of the federal injunction using the stream simulation design criteria as described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard et al. 2013). This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2022a). The crossing location can be seen in the Vicinity Map below.



Design Elements			
Floodplain Utilization Ratio	FUR: 2.1 ☐>3.0 (Unconfined) ☒<3.0 (Confined)		
Design Methodology	☒Stream Simulation ☐ Bridge		
Structure Length	*296* ft Long Structure? ☒ Yes ☐ No		
Preliminary Scour	*7.2* ft (100-year) 7.5 ft (500-year)		
Migration Risk	☒Low ☐ Not Low Scour Countermeasures? ☐ Yes ☒ Possibly ☐ No		
Gradient	2.3 % Downstream 3.3% Upstream 2.4 % Reference Reach		

Element	Requirement	Proposed
Channel Morphology	Pool-riffle	Pool-riffle
Minimum Hydraulic Width	19 feet	19 feet
Slope	3.2%	3.2%
Freeboard above the 100-year	2.0 feet	2.0 feet

Long Profile



Hydrology

Peak flows for Little Scandia Creek at SR 308

Mean recurrence interval (MRI) (years)	USGS regression equation (Region 3) (cfs)	MGSFlood (cfs)
2	6.6	**25.1**
10	13.4	**48.2**
25	16.9	**60.1**
50	19.5	**65.5**
100	22.4	**82.1**
500	29.1	**144.3**
Projected 2080 100	34.6	**127.0**

Sediment Size Summary

Comparison of observed and proposed streambed material

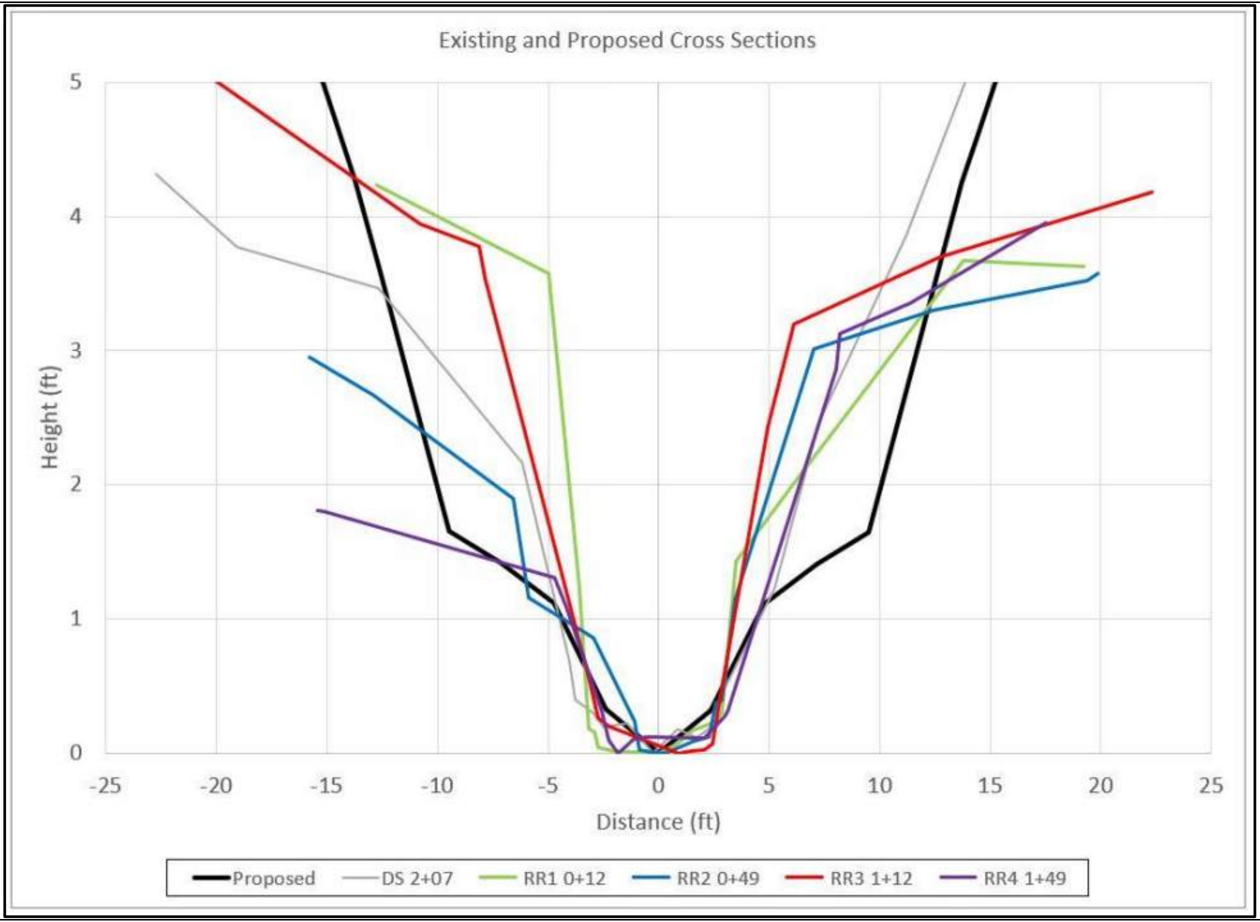
Sediment size	Observed diameter for design (in)	Proposed diameter (in)	Meander bar head diameter (in)	Meander bar tail diameter (in)
$\mathbf{D_{16}}$	0.1	0.1	0.5	0.4
$\mathbf{D_{50}}$	0.7	0.8	12.0	2.0
$\mathbf{D_{84}}$	1.5	2.0	16.1	5.7
$\mathbf{D_{95}}$	3.3	4.1	17.4	7.3
$\mathbf{D_{100}}$	4.3	6.0	18.0	8.0

The proposed streambed material should be constructed utilizing 80 percent Streambed Sediment, WSDOT Standard Specification 9-03.11(1); 10 percent 4-inch cobbles; and 10 percent 6-inch cobbles, WSDOT Standard Specification 9-03.11(2).

The head of the meander bar should consist of about 30 percent Streambed Sediment, WSDOT Standard Specification 9-03.11(1); 20 percent 12-inch cobbles, and 50 percent 12-inch to 18-inch boulders (9-03.11(2)). The meander bar tail should consist of 33 percent Streambed Sediment, WSDOT Standard Specification 9-03.11(1), and 67 percent 8-inch cobbles WSDOT Standard Specification 9-03.11(2). The meander bar head is completely stable at the 100-year flow, while the D_{84} meander bar tail is stable at 2-year flow. The stability of the D_{84} is generally regarded as the point at which the stability of the entire mixture can be measured.

Channel Shape

The proposed channel width is 10 feet, which consists of a 4-foot channel bottom with 3:1 bank slopes that extend 3 horizontal feet on each side of the channel bottom. The proposed design has channel benches on both sides of the channel (4.5-foot horizontal width at 10 percent grade) before the typical cross section resumes the 2:1 grade to tie into the existing ground. The proposed channel depth is 1.2 feet.



Habitat Complexity

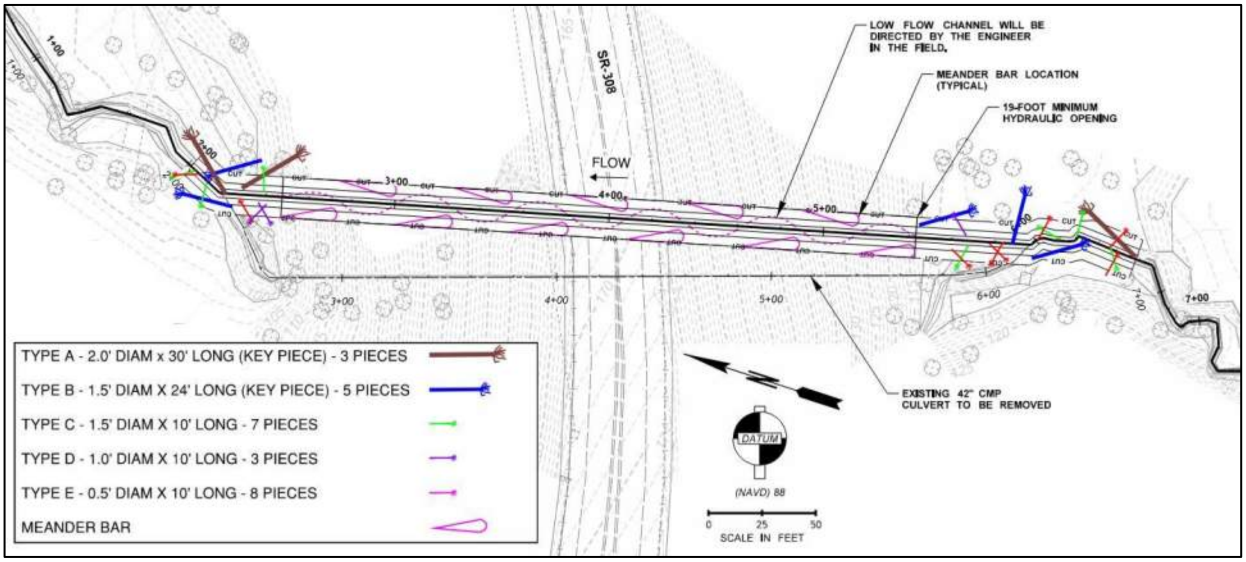
Meander bars are recommended at a minimum spacing of 27 feet through the restored channel area and at a width about one third of the structure (6 feet) to increase channel bed stability and to match the natural sinuosity of the reference reach. A total of 11 meander bars are proposed at this crossing for a culvert structure and 2 meander bars for a bridge structure.

For 450 feet of reconstructed channel, the 75th percentile wood targets, in accordance with Fox and Bolton and the WSDOT Hydraulics Manual are 15 key pieces and 52 total pieces of LWM (Fox and Bolton 2007; WSDOT 2022a). To achieve the recommended volume of wood, the LWM would need to be up to 4 feet diameter at breast height (DBH). Pieces this size would be difficult to obtain, difficult to construct, and excessive for this 10.0-foot-wide channel. For these reasons, the recommended wood volumes are reduced at this site.

Key pieces will consist of self-ballasting logs that are generally 1.5 feet to 2.0 feet DBH and 24 feet to 30 feet long. Additional pieces in the 1-foot DBH size range will be included along with smaller more mobile wood in the 0.5-foot DBH range.

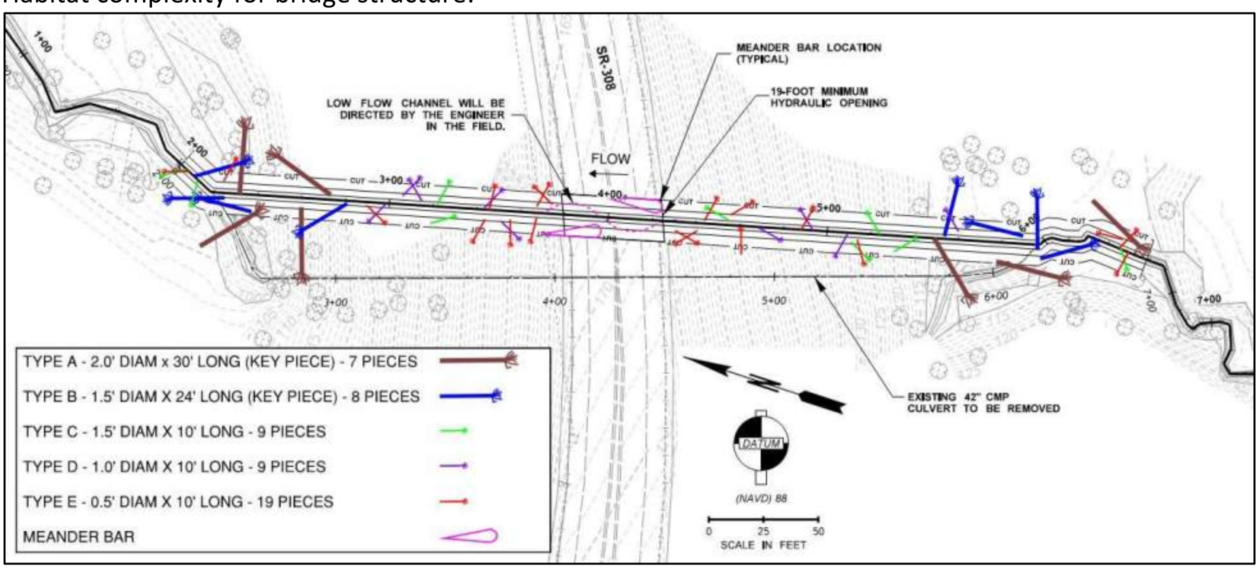
The length of modified channel outside of the crossing for a culvert type structure will be limited relative to the overall length of the crossing. As a result, placement of LWM in proximity to the crossing (less than 50 feet) will be required. The 75th percentile wood targets are not feasible for this crossing as the number and size of the LWM would be overly dense and counterproductive to fish passage. As shown in the figure below, the proposed design contains half of the targeted total number of LWM pieces and number of key pieces for a culvert type structure.

Habitat complexity for culvert structure:



The figure below shows a conceptual layout of wood recommended for this channel assuming a bridge structure is selected. Note that the increased length of open channel as compared to the culvert concept allows for the targeted total number of pieces and number of key pieces to be achieved. The LWM within the footprint of the existing roadway embankment shown in the figure below primarily remains within the minimum hydraulic opening and consists of smaller sizes of LWM to accommodate potential slope stability or shear walls that may be constructed in conjunction with a bridge structure type.

Habitat complexity for bridge structure:



Attachments:

PHD

Complexity Form with Relevant PHD Sections

WSDOT Hydraulics Section	Project Complexity Review	Prepared By: Chad Booth	Page: 1
	Project Name: SR 308 MP 1.33 Little Scandia Creek	Date: 3/8/2023	
	Stream Name: Little Scandia Creek	WDFW ID Number: 992008	
	Tributary to: Liberty Bay, Puget Sound	State Route/MP: SR 308 MP 1.33	

General Instructions:

The complexity form that was filled out during Site Visit 3 (and any updates between Site Visit 3 and PHD) is used to fill in the Levels of Complexity below. WDFW will utilize this form to review the relevant sections of the PHD and provide comments based on Requirements.

The relevant sections listed below not bolded are standard from this template. Any sections listed in bold are sections that are added for consideration by the design team to the element to provide further clarity.

Category	Project Elements	Levels of Complexity			Relevant PHD Section(s)
		Low	Med	High	
Stream Design Factors (alignment, profile, bed mix)	Channel realignment		X		4.1.2
	Stream grading extents		X		Appendix C; Section 4
	Expected stream movement (migration)	X			2.7.5
	Gradient (morphology)		X		2.6.4
	Slope ratio		X		4.1.3
	Sediment supply	X			2.3

Category	Project Elements	Levels of Complexity			Relevant PHD Section(s)
		Low	Med	High	
Structure Factors	Stream size and bankfull width	X			Section 2.
	Meeting requirements for freeboard	X			4.2.3
	Fill depth above barrier		X		4.2.3
	Risk of degradation/aggradation		X		7
	Long culvert criteria/openness ratio		X		4.2.4
	Channel confinement & Floodplain Utilization Ratio (FUR)		X		2.7.2.1, Entire Section 5, Appendix E, Appendix H, Appendix I
	Meeting Stream Simulation	X			Summarized in table
	Tidal influence	X			N/A for medium complexity sites as this automatically kicks project to high complexity
	Alluvial fan	X			N/A for medium complexity sites as this automatically kicks project to high complexity
	Presence of other barriers nearby	X			Section 2 throughout, potentially Sections 4 and 5 if barrier influences design
	Potential for backwater impacts	X			Section 6
	Presence of infrastructure nearby		X		2.6.2 Existing Conditions
	Need for bank protection	X			8, Appendix M
	Geotech or seismic considerations	X			2.3

SR 308 MP 1.33 Little Scandia Creek (992008): Preliminary Hydraulic Design Report

JULIE HEILMAN, P.E., WSDOT STATE HYDRAULICS ENGINEER,
WSDOT HEADQUARTERS HYDRAULICS OFFICE
(FPT22-00157)
Y-12554 Olympic Region GEC

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OLYMPIC REGION GEC FISH PASSAGE AND STREAM DESIGN ADVISOR (SDA):
Nicholas VanBuecken, PE - FPT 20-08789 - Jacobs

LIST OF CONTRIBUTING ENGINEERS, GEOMORPHOLOGISTS, AND BIOLOGISTS:

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Mike Rice, PE, Engineer, David Evans and Associates, Inc. Portland, OR (FPT20-40474)
Bryan Darby, Biologist, David Evans and Associates, Inc., Bellevue, WA (FPT20-39955)

ROLES AND RESPONSIBILITIES FOR THIS PHD

The roles and responsibilities of the key individuals in developing this Preliminary Hydraulic Design (PHD) are defined as follows for the Olympic Region GEC:

PHD Lead PE
Responsibility: Water Resources Professional Engineer in responsible charge of this Hydraulic Design Report, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices.

Authoring Firm PHD QC Reviewer(s)
Responsibility: Qualified independent individual(s) responsible for the detailed checking and reviewing of hydraulic and stream design documents prepared by the authoring firm, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices. Before submittal to the GEC, the authoring Firm Quality Control (QC) Review shall be performed in accordance with the QC methods identified in the quality assurance document Technical Verification Form (TVF). The QC methods are defined in the Olympic Region GEC Quality Management Plan (QMP) Section 5.3 and the QMP Supplement developed specifically for Y-12554 Task AC.

Olympic Region GEC Fish Passage/Stream Design Advisor
Responsibility: Water Resources Professional Engineer providing mentorship, process oversight, quality check issue resolution, and recommendations in the approach to hydraulic analysis and design performed by the **PHD Lead PE**. Before submittal of draft deliverables from the GEC to either the PHD Lead or WSDOT Headquarters, the Olympic Region GEC Fish Passage/Stream Design Advisor will review and refine GEC comments and confirm GEC comment resolution by the **PHD Lead PE**.

Americans with Disabilities Act (ADA) Information

Materials can be made available in an alternative format by emailing the WSDOT Diversity/ADA Affairs Team at wsdotada@wsdot.wa.gov or by calling toll free: 855-362-4ADA (4232). Persons who are deaf or hard of hearing may contact that number via the Washington Relay Service at 7-1-1.

Title VI Notice to Public

It is Washington State Department of Transportation (WSDOT) policy to ensure that no person shall, on the grounds of race, color, national origin, or sex, as provided by Title VI of the Civil Rights Act of 1964, be excluded from participation in, be denied the benefits of, or be otherwise discriminated against under any of its federally funded programs and activities. Any person who believes his/her Title VI protection has been violated may file a complaint with WSDOT’s Office of Equal Opportunity (OEO). For Title VI complaint forms and advice, please contact OEO’s Title VI Coordinator at 360-705-7082 or 509-324-6018.

Contents

Figures

Tables

1 Introduction

To comply with United States et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the State Route (SR) 308 crossing of Little Scandia Creek at milepost (MP) 1.33 within WSDOT's Olympic region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier [ID] 992008) and has an estimated 3,694 linear feet (LF) of habitat gain.

Per the federal injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated the crossing using the stream simulation method because of the relatively small bankfull width (10.0 feet) and the confined nature of the channel. SR 308 is an essential access road to local residents in Kitsap County and cannot be avoided.

The crossing is located in Kitsap County, 6 miles north of Silverdale, Washington, in WRIA 15. The highway runs in an east-west direction at this location and is about 5,070 feet from the confluence with Liberty Bay. Little Scandia Creek generally flows from south to north beginning 3,694 feet upstream of the SR 308 crossing (see Figure 1 for the vicinity map).

The proposed project will replace the existing 313.6-foot-long, 3.5-foot-diameter round corrugated metal pipe (CMP) culvert with a structure designed to accommodate a minimum hydraulic width of 19 feet. The proposed structure is designed to meet the requirements of the federal injunction using the stream simulation design criteria as described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard et al. 2013). This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2022a). WSDOT Headquarters (HQ) Hydraulics is not recommending a structural type for the project; it will be determined by others at a future design phase.

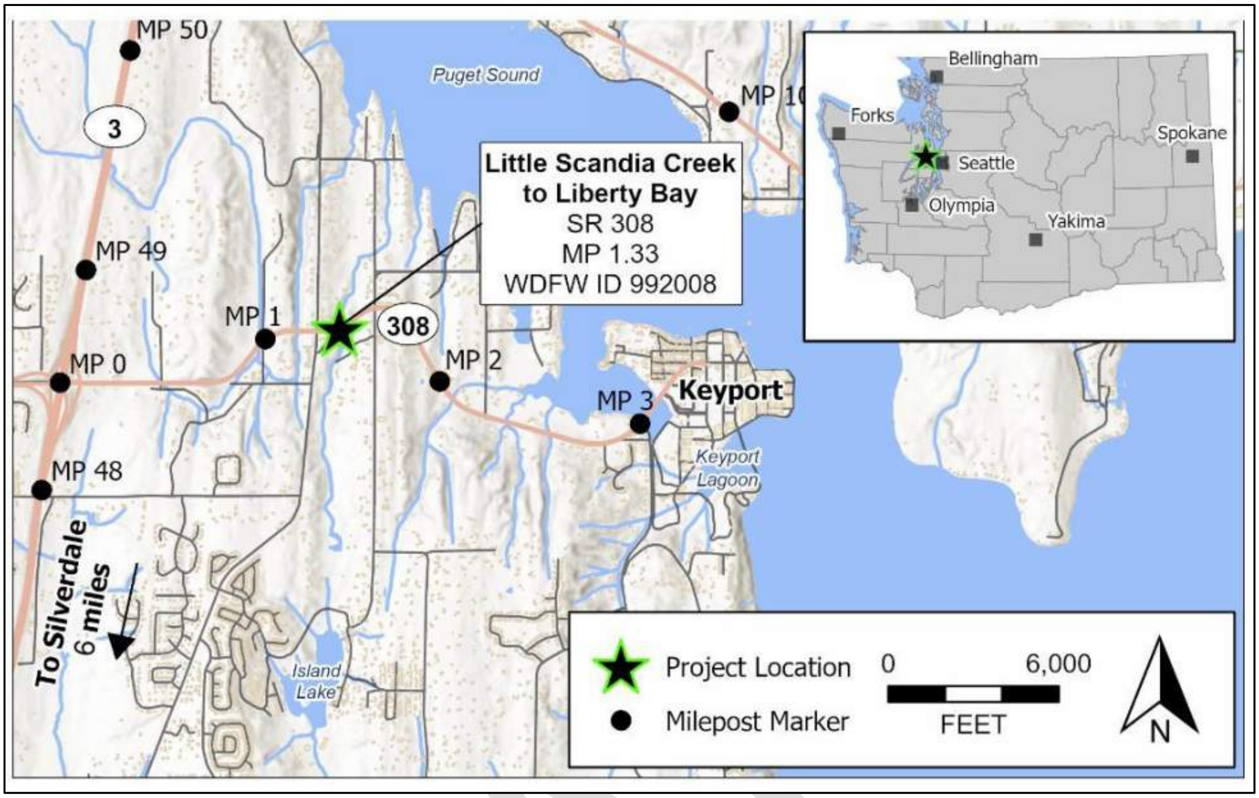

Figure 1: Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. This was performed using a site visit and desktop research with resources such as the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and WDFW, and past records like observations and fish passage evaluation. All elevations detailed in this report, unless stated otherwise, are referenced against the North American Vertical Datum of 1988 (NAVD88).

2.1 Site Description

The culvert under SR 308 at MP 1.33 (Site ID 992008) for Little Scandia Creek to Liberty Bay is listed as a barrier due to excessive slope. The culvert drops a little less than 8 feet over 313.6 feet, resulting in a slope of 2.53 percent. In addition, there is a drop on the downstream side of the crossing of almost 1 foot. These conditions can create flow conditions that inhibit the ability of adult and juvenile fish to access habitat upstream of the crossing. This crossing is not listed as a Chronic Environment Deficiency or failing structure (WSDOT 2020). A site visit noted no visible maintenance activity, and no maintenance records were available for this crossing. The culvert and adjacent drainage ditches are clear of debris. The site visit did note some evidence of flooding/backwater conditions on the right bank of the creek upstream of the crossing, however there is no record of flood history in the surrounding area. The total length of upstream habitat gain for Site ID 992008 is 3,694 linear feet according to the WDFW Fish Passage and Diversion Screening Inventory Database (WDFW 2010) for this site.

2.2 Watershed and Land Cover

Little Scandia Creek has no major tributaries and drains approximately 0.28 square mile. The watershed of the contributing basin above the existing culvert was delineated by reviewing topographical data obtained from light detection and ranging (LiDAR) survey data (see the watershed map in Figure 2). The basin is bounded by a high point near Lone Maple Lane NW to the south, SR 308 to the north, Silverdale Way NW to the west, and Central Valley Road NW to the east. The basin's maximum and minimum elevations are 375.8 feet and 96.0 feet, respectively. From the southern high point to SR 308, the basin is relatively steep, with an average slope of approximately 3.16 percent. The creek flows through a lightly forested area mixed with light residential development. According to the USGS National Land Cover Database (2019), basin landcover is 56 percent developed (open space to medium density), 41 percent forested (deciduous, evergreen, and mixed), 1 percent wood wetlands, and 2 percent grassland (see Table 1). The wooded areas are concentrated in the center of the basin along the creek alignment, while low density development lines the edges of the basin near the bounding roadways (see Figure 3). The basin receives annual average precipitation of 40.9 inches (PRISM Climate Group 2021).

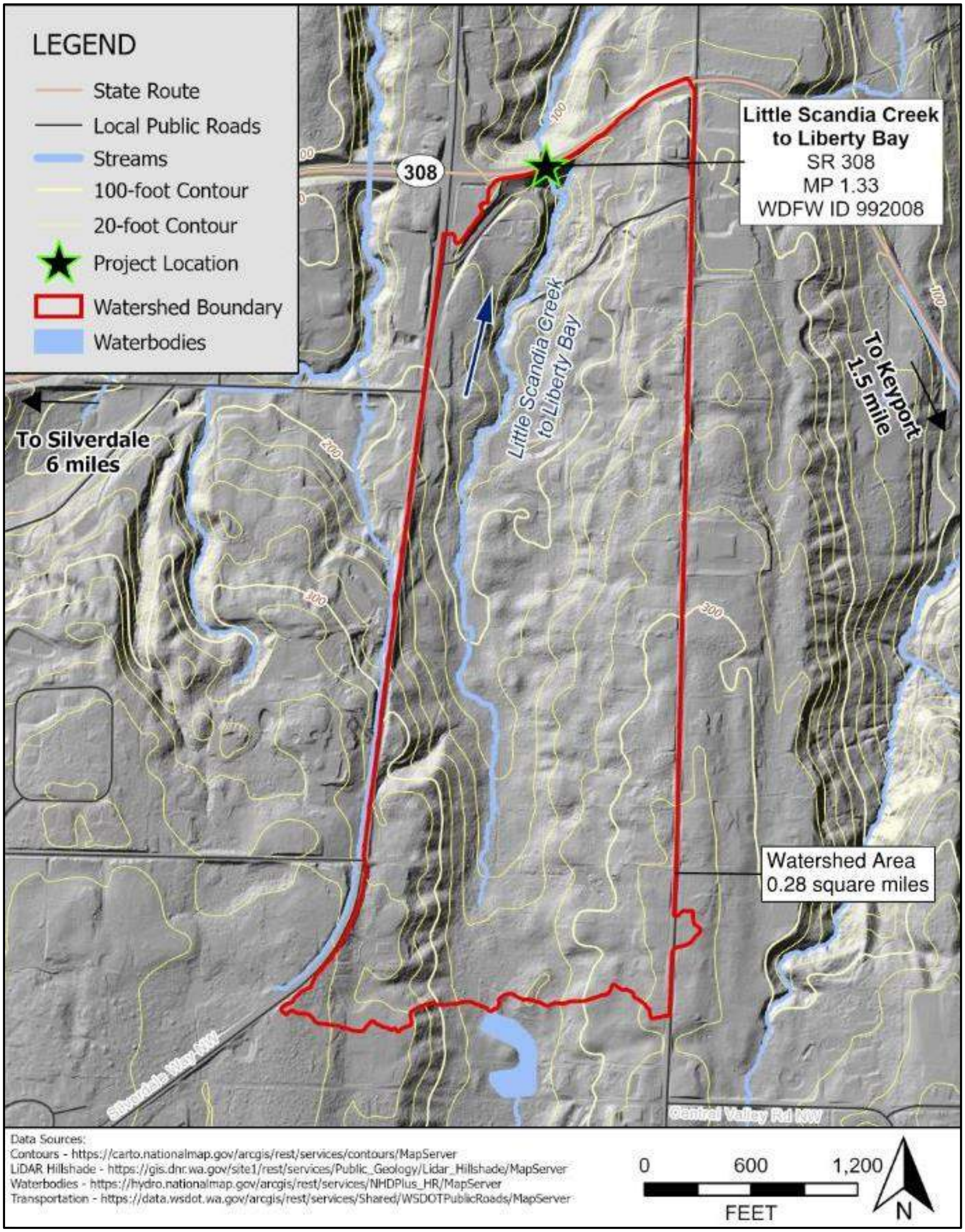

Figure 2: Watershed map

Table 1: Land cover

Land cover class	Basin coverage (percentage)
Developed, Open Space	33%
Developed, Low Intensity	19%
Developed, Medium Intensity	4%
Deciduous Forest	14%
Evergreen Forest	14%
Mixed Forest	13%
Grassland/Herbaceous	2%
Woody Wetland	1%

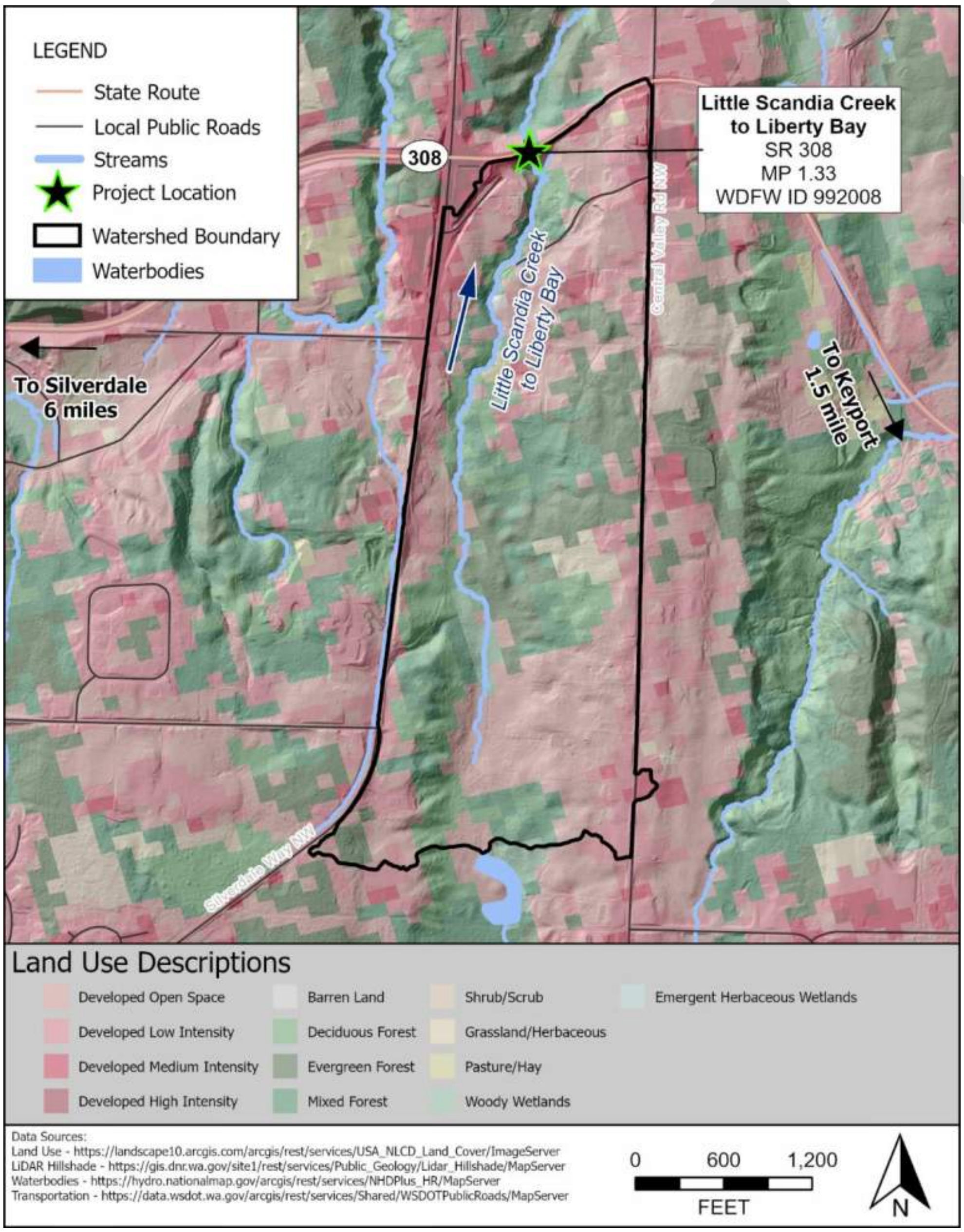

Figure 3: Land cover map (NLCD 2019)

2.3 Geology and Soils

Kitsap Peninsula consists of glaciated surfaces that are fluted with multiple parallel ridges and pockmarked with irregular depressions (see Figure 4). This Puget Lowlands topography is shaped by glacial and non-glacial processes (Haugerud 2009). The glaciers eroded and deposited material with each advance and retreat. The last ice sheet retreated approximately 16,400 calculated years before the present day (Porter and Swanson 1998). Pleistocene continental glacial drift is the primary geologic unit deposited in the project area (DNR Geology Portal n.d.). Continental glacial drift is primarily composed of sand with local pebbles and silt. Non-glacial deposits include alluvium and colluvium from fluvial and hillslope transport. Urbanization of the watersheds has increased runoff and sediment supply to the streams. General geology for the Puget Lowlands includes frequent landslides, and these landslides also add to the sediment supply. Based on a review of available LiDAR data, the area approximately 240 feet upstream of the Little Scandia Creek crossing appears to be influenced by a historical landslide. The approximate date of the landslide is unknown, but it appears to have shifted the alignment of the creek and confined it along the left side of the valley (see Section 2.6.2). This landslide area appears to be a consistent source of sediment as the creek gradually adjusts to a new equilibrium. As the historical landslide appears stable, the design of the proposed crossing will not be influenced by potential landslides unless future geotechnical work finds the adjacent slopes to be unstable.

Figure 5 details the expected soil series within the project area and the drainage basin of Little Scandia Creek. The soil in the drainage basin consists of sandy and silty loams, and there is minimal presence of large cobbles and boulders. The undercut roots, root forced step pools, and steep channel banks shown in Section 2.6 photos are signs of erosion and incision in the system. The WSDOT HQ Geotechnical Scoping Lead provided additional geotechnical data dated September 7th, 2022. The additional data included three soil borings along the alignment of the existing culvert crossing of SR 308. Soil data from the borings, which ranged in depth from 36 feet to 72 feet, consistently reported silty and sandy gravel soils. The geotechnical report provided by WSDOT also included a historical report of a 1.5:1 (H:V) cut slope failure along SR 308 0.4 mile east of the existing SR 308 Little Scandia Creek crossing and a roadway design project starting 0.1 mile west of the existing crossing and extending 2 miles east of the existing crossing proposing 2.5:1 (H:V) cut slopes.

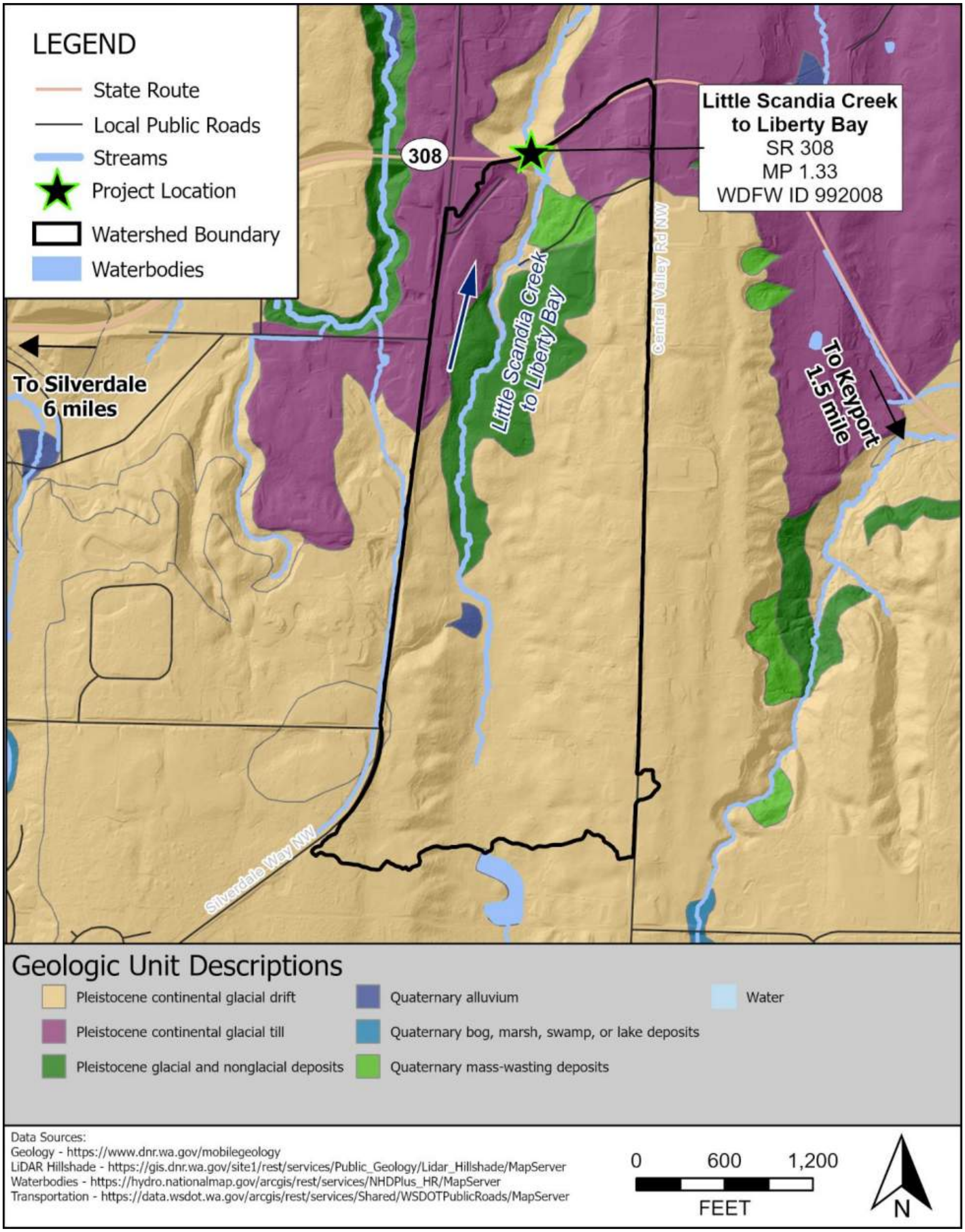

Figure 4: Geologic map

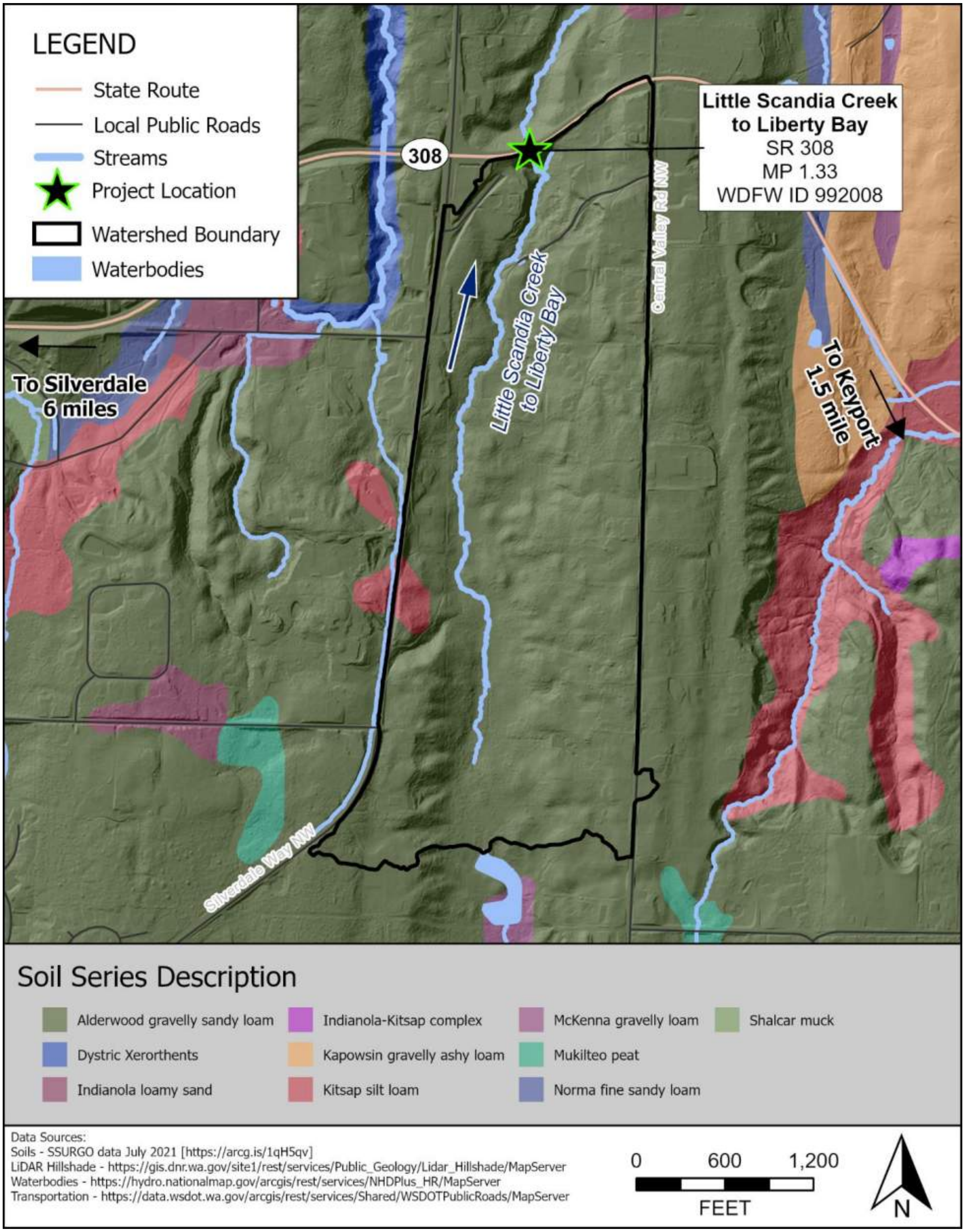

Figure 5: Soils map

2.4 Fish Presence in the Project Area

Table 2 provides a list of salmonid species documented, and presumed to be found, in Little Scandia Creek, a tributary to Liberty Bay, Puget Sound. Documented salmonids in the stream are coho salmon (*Oncorhynchus kisutch*), fall chum salmon (*Oncorhynchus keta*), and coastal cutthroat trout (*Oncohynchus Clarki clarki*) (WDFW 2022). Resident trout (*Oncorhynchus mykiss*) are presumed to be present in Little Scandia Creek as indicated by the Reduced Survey Full Survey identifying stream characteristics and habitat features (WDFW 2022). Information was gathered from the WDFW Fish Passage and Diversion Screening Inventory Database report (WDFW 2010).

Table 2: Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Coho Salmon (*Oncorhynchus kisutch)*	Documented	WDFW	Not Listed
Fall Chum Salmon (*Oncorhynchus keta*)	Documented	WDFW	Not Listed
Coastal Cutthroat Trout (*Oncorhynchus Clarki clarki)*	Documented	WDFW	Not Listed
Resident Trout (*Oncorhynchus mykiss*)	Presumed	WDFW	Not Listed

2.5 Wildlife Connectivity

Wildlife connectivity will only be included in the FHD if wildlife connectivity is included as part of the project.

2.6 Site Assessment

2.6.1 Data Collection

WSDOT provided a topographic survey of Little Scandia Creek from approximately 270 feet downstream of SR 308 to approximately 250 feet upstream (see Appendix D). David Evans and Associates, Inc. (DEA) visited the project site on December 17, 2021, to conduct a stream assessment and collect data needed to support development of preliminary design information (Site Visit 2). Site Visit 1 was conducted by WSDOT, at a previous date, to determine the extents of the survey and identify visible hydraulic constraints. Co-managers also visited the site at a previous date to produce the WDFW Fish Passage and Diversion Screening Inventory Database report (WDFW 2010). The existing crossing is a 313.6-foot-long, 42-inch-diameter round CMP culvert. The upstream reach flows through a deep ravine bound by low density development (see Figure 3). The downstream reach flows though property that is wooded and similarly developed.

The DEA team observed local stream and drainage basin conditions 300 feet upstream and 500 feet downstream of the crossing. Appendix B provides a summary of the site visit. DEA measured bankfull width (BFW) at five locations—two upstream and three downstream of the crossing. A reference reach upstream of the crossing was chosen during this initial site visit because it more closely matched the expected slope of the crossing, and the channel appeared stable. Fish habitat was not a driving factor in reference reach selection, as the stream had consistently high-quality fish habitat. The average BFW of the two BFW measurement locations in the reference reach was 8.5-feet. Three pebble counts were performed in the field—two upstream and one downstream of the crossing. The results of the upstream pebble count (PC2) were disregarded because this section of the creek was determined to be impacted by backwater from the existing crossing. The backwater extents were determined during existing conditions hydraulic modeling. Results of the existing conditions hydraulic modeling showing backwater extents are contained in Appendix H. Section 2.7.3 summarizes the results of the pebble counts.

DEA visited the site again on February 3, 2022 (Site Visit 3) with WSDOT, WDFW staff, and Suquamish Tribal representatives (the co-managers). DEA and the co-managers measured BFW at eight locations—three upstream and five downstream of the crossing. Figure 6 shows a plan view of the site and where these measurements were taken. During this site visit, the co-managers suggested that the upstream reach appears to be impacted by a historical landslide and that the creek alignment and channel shape may not represent a state of equilibrium. Due to this potential influence, the co-managers were not comfortable using the three upstream BFW measurements, and the reference reach was shifted to downstream of the crossing. The downstream reach is not as steep as the upstream reach, so the new reference reach was identified in the steepest part of the downstream reach that contained stable channel banks and good fish habitat. The average BFW at the five downstream cross-sections was 9.2 feet (see Section 2.7.2). The co-managers requested that the average BFW be rounded up to 10.0 feet. Concurrence of the reference reach location and 10.0-foot BFW was reached during Site Visit 3.

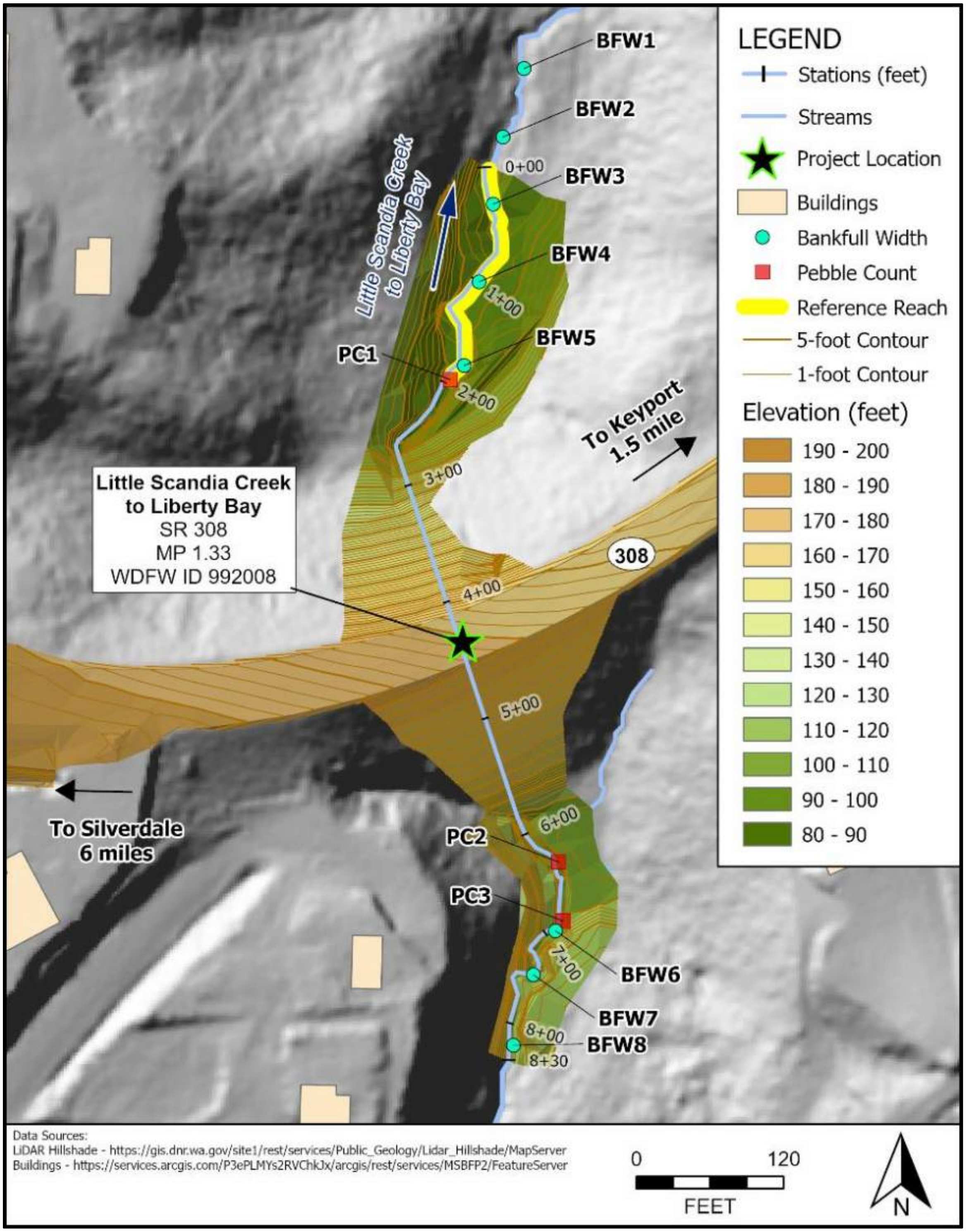

Figure 6: Reference reach, bankfull width, and pebble count locations

2.6.2 Existing Conditions

A review of as-built information for this section of SR 308 provided by WSDOT did not reveal any information pertaining to the crossing in these documents. Based on survey information, this crossing consists of one 42-inch-diameter round CMP culvert that is 313.6 feet long (see Figure 7), has a grade of 2.5 percent, approximately 60 feet of fill depth, and crosses SR 308 at a perpendicular angle. WDFW has identified this crossing as a fish barrier due to slope (Site ID 992008). Visual inspection indicates that the culvert appears to be in relatively good condition and has minor rusting along the invert, though the bottom of the culvert outlet flare is completely degraded. A scour pool 0.5 feet deep was present at the culvert outlet. The length of the scour pool was not recorded during the site visits.

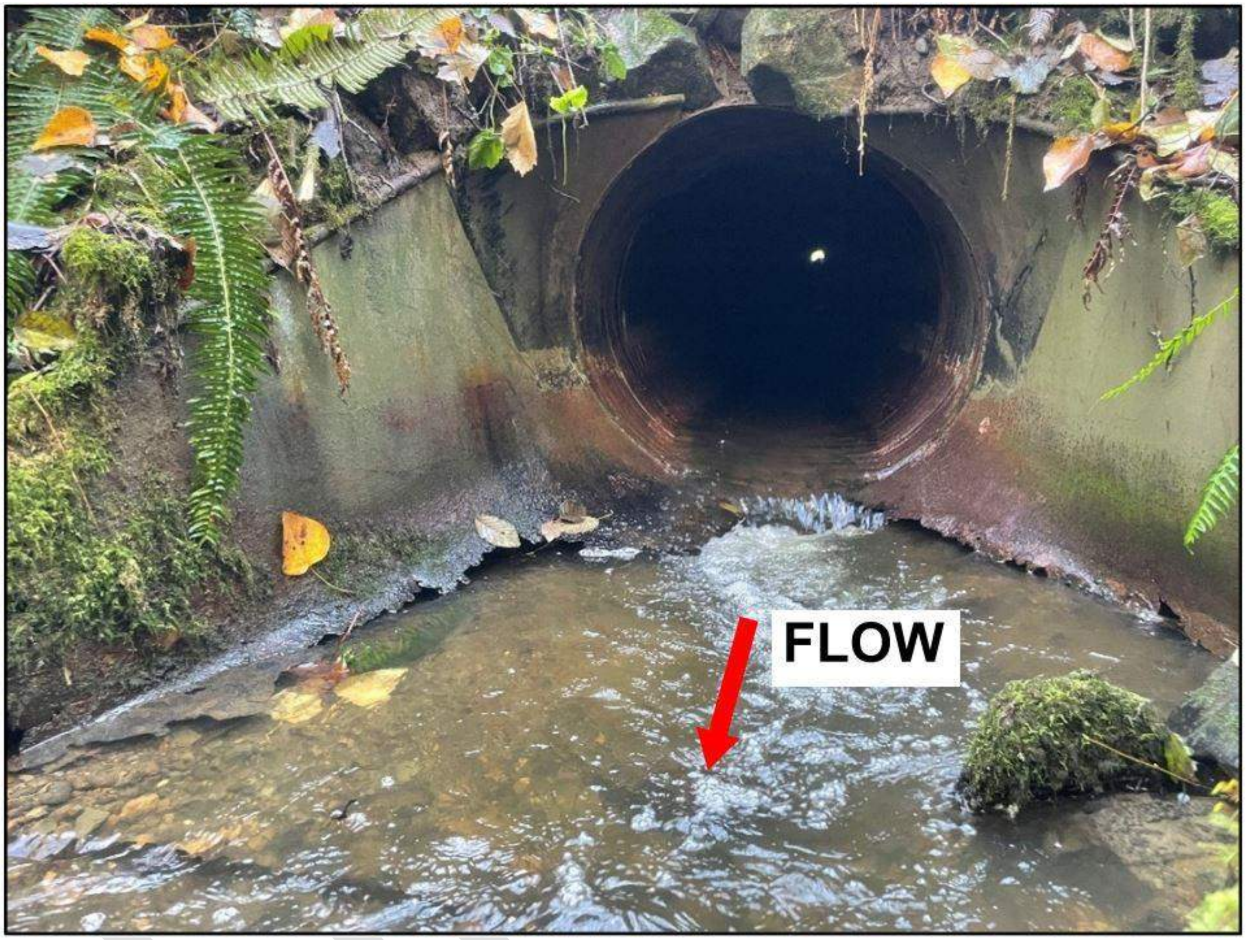

Figure 7: Outlet of existing 42-inch CMP culvert, looking upstream

The site assessment (Site Visit 2) began at approximately station 8+30 (see Figure 6 for creek stationing) at the upstream survey limits, approximately 250 feet upstream of the SR 308 crossing, and proceeded downstream. For the observed upstream section of Little Scandia Creek, channel slopes range from 2.9 to 3.5 percent. Based on a review of available LiDAR during Site Visit 3, the upstream extents of the study area appear to be impacted by a historical landslide. WSDOT and co-manager staff noted the presence in the area of an apparent scarp, which would be indicative of a landslide. The landslide appears to be stable, though it does contribute sediment to the system. The creek is confined through this upstream section impacted by the historical landslide, and the alignment appears to be shifted along the left edge of the historical ravine (see Figure 8). The banks are steep and inaccessible to flow even during large storm events. Floodplain terraces are not present.

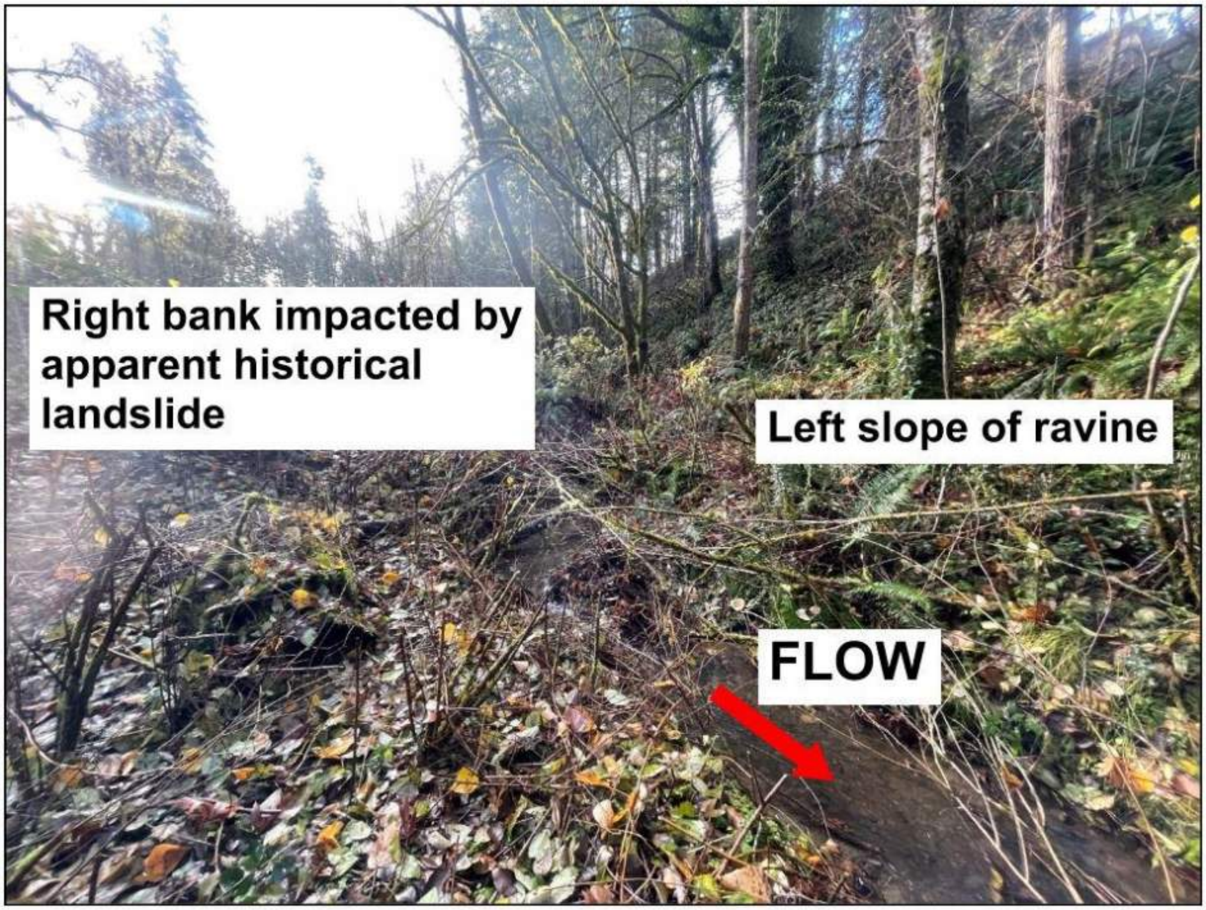

Figure 8: Creek alignment between ravine slope and apparent historical landslide, looking upstream

Within this stretch of the creek near station 7+20 and in the area influenced by a historical landslide, two approximately 12-inch-diameter trees are centered in the channel and had created a shallow blockage due to debris accumulation (see Figure 9). The size and type of debris accumulated indicates that the blockage is likely transitory and washes out during larger flow events. Survey data indicate that there is an approximate drop of 2 feet from upstream to downstream at the blockage due to the transitory tree roots feature in the stream. When the tree roots are no longer present, a slight regrade lowering the thalweg upstream of the blockage would likely occur.

Figure 9: Trees within channel, along with transitory debris accumulation and 2-foot drop in channel, looking upstream

Just upstream of the crossing, from station 6+60 to station 5+80, the creek alignment and ravine do not appear to be impacted by the historical landslide (see Figure 10). The floodplain is much less confined here and has a large flat area along the right bank upstream of the crossing which may be an unverified wetland. This area appears to stay consistently wet and is easily accessible during most flows above the bankfull event.

Figure 10: Transition between landslide-impacted channel and flatter floodplain upstream of crossing, looking upstream

Near station 6+30, the channel is bound by three large cedar trees. The roots of the trees have stabilized the channel bed material at this location, which has caused an approximate 9-inch step to form in the channel. Downstream of the step, a 2-foot-deep scour pool (8 feet by 14 feet) has formed as flows undercut the base of the most downstream cedar (see Figure 11 and Figure 12). Sandy material has accumulated in the pool which may be a result of the backwater condition caused by the existing culvert during large flow events. This sandy bed material is inconsistent with the bed material elsewhere in the channel, which is dominated by coarse material ranging from fine gravels to cobbles (see Section 2.7.3).

Figure 11: Scour pool at base of cedar trees near station 6+30, looking upstream

Figure 12: 9-inch step and 2-foot scour pool at base of cedar trees near station 6+30, looking upstream

An apparently abandoned private water pump and concrete vault are located along the left bank of the channel near station 6+10 (see Figure 13). The vault measures approximately 4 feet by 4 feet and does not have a top slab. The internal pump is in disrepair and does not appear to be functional (see Figure 14).

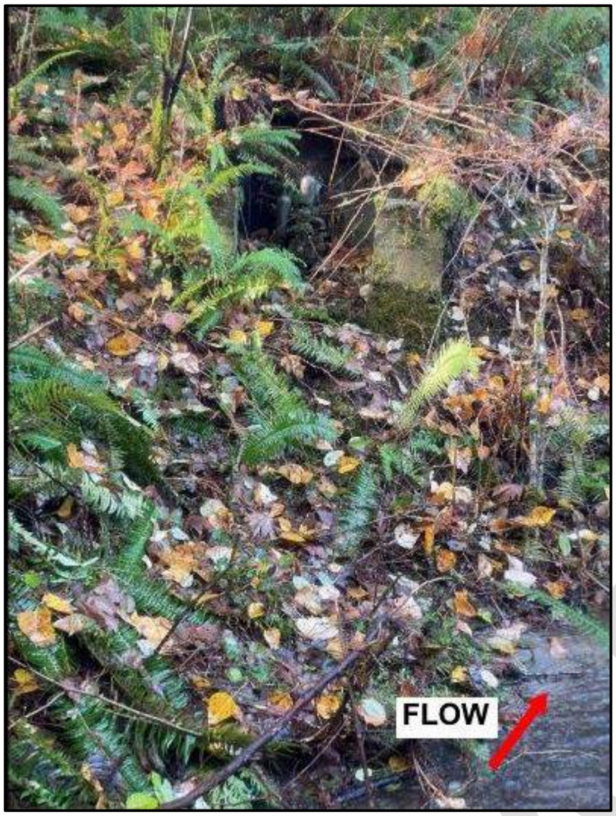

Figure 13: Private water pump vault on left bank of channel near station 6+10, looking downstream

Figure 14: Unmaintained pump inside of private water vault

Immediately upstream of the inlet of the crossing, a highway conveyance ditch from SR 308 connects to the left side of the Little Scandia Creek channel. Flow was observed in this ditch during the November 29, 2021 assessment (Site Visit 2) (see Figure 15). LiDAR information indicates the existence of a similar highway conveyance ditch from SR 308 that drains to the right side of Little Scandia Creek, but no ditch or source of flows was identified during field investigations.

The inlet of the culvert is in good condition and shows no signs of degradation or aggradation of sediment. There is some minor rusting along the invert of the CMP culvert, but no significant deformation or damage was observed. The upstream end of the culvert is overtopped by approximately 60 feet of fill that makes up the embankment of SR 308 (see Figure 15).

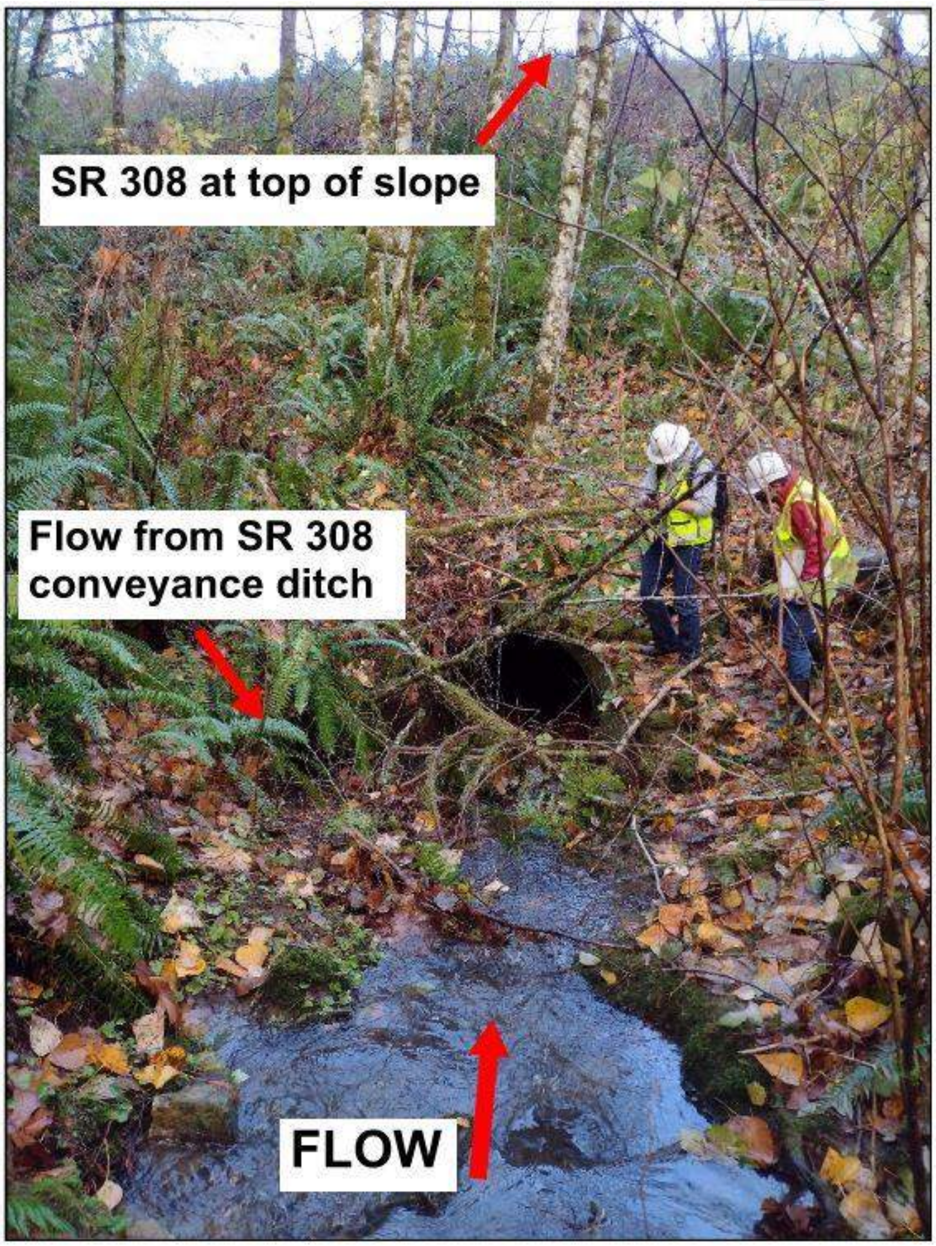

Figure 15: Crossing inlet showing confluence with SR 308 ditch and 60 feet of fill, looking downstream

SR 308 above the crossing is a two-lane highway, generally in an east-west orientation. The travel lanes are bounded by wide shoulders and guardrail, having both a vertical and horizontal curve, with the roadway superelevated to the south. The downhill side of the roadway is also bounded by a drainage curb that has an inlet located at the low point of the vertical curve. The outlet of the existing culvert is overtopped by approximately 60 feet of fill that makes up the embankment of SR 308. At the outlet of the crossing, the culvert invert has largely rusted away, and localized scour of approximately 9 inches has occurred (see Figure 16). The creek alignment at the outlet of the culvert near station 2+60 makes a 90-degree bend to the east. The outside edge of this bend along the left bank of the channel is bounded by a 3-foot-tall rock wall (see Figure 17). The rock wall appears to be in stable condition and shows no signs of sloughing or degradation along the base.

Figure 16: Outlet of crossing showing rusted invert and scour hole, looking upstream

Figure 17: Rock wall along the left bank at outlet of the culvert, looking upstream

Little Scandia Creek downstream of the crossing is slightly flatter than upstream; its slopes downstream range from 2.3 percent to 2.7 percent. There are no indications of historical landslides in this area, and the channel appears to be in a natural alignment. The channel is relatively confined, and there is limited access to the overbank areas during larger flow events (see Figure 18).

Figure 18: Confined downstream channel with 60 feet of fill above crossing, looking upstream

Unlike the upstream reach, the downstream reach exhibits more channel complexity, including a few channel-spanning logs (see Figure 19 and Figure 20). Existing habitat for fish lies primarily downstream of the culvert through this section. The presence of large woody material (LWM) and adequate canopy cover provide juvenile coho (observed during Site Visit 3), chum salmon, and trout salmonids with adequate rearing habitat. Downstream and immediately upstream of the culvert woody material and adequate canopy cover create habitat for adult and juvenile salmonids. The presence of overstory canopy and gravel material provides some opportunity for juvenile salmonids to find adequate cover and materials for rearing, though the wide and shallow channel is not ideal. The historical landslide impacts do not provide spawning potential in the reaches upstream of the culvert. Floodplains that are accessible immediately upstream and downstream of the culvert provide sheltering habitats for salmonids during high flow events.

The site assessment ended approximately 350 feet downstream of the culvert. Throughout the evaluated section of the creek, the culvert and adjacent drainage ditches were clear of debris, although there were no signs of maintenance activity. No WSDOT maintenance records were available for this site to confirm that assessment.

Figure 19: Channel spanning LWM near station 2+40, looking upstream

Figure 20: Channel spanning LWM near station 1+20, looking downstream

2.6.3 Fish Habitat Character and Quality

WDFW classifies the SR 308 culvert for Little Scandia Creek as 0 percent passable because of slope (WDFW 2010). Fish presence and use of the site were documented in a 2010 site visit by WDFW, during which juvenile coho salmon were documented downstream of the culvert. Other documented species in the creek are fall chum salmon and coastal cutthroat trout. Resident trout are presumed to be in the creek as indicated by the Reduced Survey Full Survey (WDFW 2022). A DEA fish biologist visited the site on December 1, 2021 to inform this PHD report (see Section 2.6.1).

Upstream of the culvert, the stream has a pool-riffle and step-pool morphology with high-quality fish habitat. Mature cedar trees line the edges of the creek, providing good cover and shade to the stream, and additional habitat in the form of root undercutting. Minimal large rocks within the stream contribute to stream diversion, providing both pools for juvenile salmonids and resting areas for mature fish migrating upstream. Spawning gravels are present but not abundant in this section of the creek. No estuaries or tidally influenced areas are within the vicinity of the crossing, either upstream or downstream. An unverified wetland may be located upstream of the existing culvert.

Downstream of the culvert, the stream has a plane-bed morphology, and spawning habitat is more abundant than rearing habitat for juvenile salmonids. The channel in this section of the stream is straighter, varies more in width, and features no significant pools. The substrate here features more gravel and cobble and is more adequate for spawning habitat. Western redcedar (*Thuja plicata*), western hemlock (Tsuga heterophylla), cottonwood (*Populus trichocarpa*), red alder (*Alnus rubra*), and bigleaf maple (*Acer macrophyllum*) trees provide the stream with adequate canopy cover, and salmonberry (*Rubus spectabilis*) and swordfern (*Polystichum munitum*), provide additional cover to the edges of the stream. Juvenile coho were observed in the downstream section of the creek.

Overall, current conditions support spawning habitat in the creek sections downstream of the culvert, and more adequate rearing habitat is upstream of the culvert. Coho salmon, coastal cutthroat trout, and resident trout would benefit most from gaining access to the upstream reach.

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

The riparian area along the left and right banks of the creek has well-established trees, primarily western redcedars creating good canopy cover, and an understory of ferns and native shrubs (see Figure 21), except for the areas immediately upstream and downstream of the crossing. This area, from approximately station 6+50 to station 2+70, has been impacted by the construction of SR 308 and is characterized by the presence of smaller red alders and an understory of ferns. The transition between red alders and western redcedars near station 2+70 likely indicates the limits of disturbance when the road was constructed (see Figure 22). Immediately upstream of the crossing, the riparian area is flatter and less confined than the other reaches of the creek. This area appears to be consistently wet and is characterized by smaller brush-like material with minimal ferns (see Figure 10). No noxious weeds were noted during the site visits.

Figure 21. Riparian buffer along reference reach, looking downstream

Upstream of the crossing, very little LWM was present in the creek. There were some trees adjacent to and within the channel that created steps, pools, or refuge areas in the form of temporary debris accumulation and root undercuts (see Figure 9 and Figure 11). The limited amount of LWM could be due to the impacts of the historical landslide and the more confined nature of the channel, though future wood recruitment is expected as the upstream channel continues to trend towards equilibrium. Downstream of the culvert, woody material within the channel or spanning over the channel was more frequent (see Figure 19). The density of vegetation is relatively consistent between the upstream and downstream reaches. The disparity in LWM could be due to a historically more stable alignment for the creek, and the capacity-limited culvert could be dampening peak flow events such that flows downstream of the crossing are less capable of moving LWM. The observed LWM is generally above typical flow depths and has limited impact on the stream channel. Future recruitment of wood to the downstream reach is possible and could create channel-forming features in the form of scour holes and steps.

No indications of beaver presence or activity were observed upstream or downstream of the crossing, and the presence of beavers is not expected in the future.

Figure 22: Transition between alders and western red cedars along the downstream end of the crossing, likely showing the extents of the roadway construction impacts

2.7 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, the geometry and cross sections of the channel, and stability of the channel both vertically and laterally of Little Scandia Creek.

2.7.1 Reference Reach Selection

The reference reach is a 190-foot segment of the stream that begins approximately 90 feet downstream of the culvert outlet, 240 feet from the centerline of SR 308 MP 1.33, and extends to the limits of survey data, a distance approximately 270 feet downstream (station 0+00) of the barrier outlet (see Figure 6 and Figure 23). The reference reach was selected by finding a portion of stream that matches the upstream gradient as closely as possible in a stable reach with good habitat not influenced by the upstream historical landslide. More information about the data collection and decision-making pertaining to reference reach selection during Site Visit 2 and Site Visit 3 with co-managers is contained in Section 2.6.1. The reference reach is moderately confined, having steep hillslopes on either side of a narrow overbank area. The overbank areas are readily accessible during flood events, and the channel is not incised. The average channel slope in the reference reach is approximately 2.4 percent (ranges from 2.3 percent to 2.7 percent), based on available survey data.

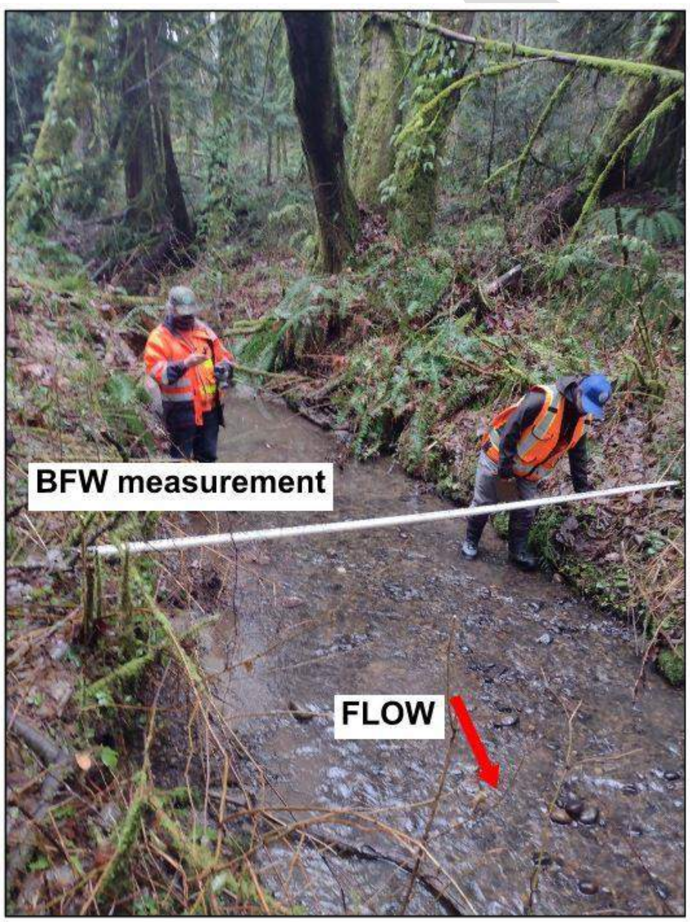

Figure 23: Reference reach looking upstream at location of BFW4 (10.5 feet), approximately 185 feet downstream of crossing

The channel bed of the reference reach consists of fine gravels to cobbles, and a few locations with fines and sand. Large riffle-forming rocks are present as well but do not protrude above the channel bed, so the size of the rocks cannot be estimated. Sandy depositional areas were observed at the channel fringe in locations where eddies are likely to form during high flows due to obstructions from trees and woody material.

The channel upstream of the barrier was considered as a reference reach; however, because of the impacts of the historical landslide and backwater conditions created by the capacity-limited crossing, this reach was deemed unsuitable. Despite these conditions, the channel cross sectional geometry and BFW are consistent upstream and downstream of the barrier. Because of the impacts of the historical landslide on the stream sinuosity, meander belt widths were not analyzed for the upstream section of the stream affected by the historical landslide. Meander belt width measurements using LiDAR, upstream of the area affected by the historical landslide, are similar to the downstream meander belt widths discussed below.

Survey of the reference reach indicates that the channel slope in the reference reach is on average 2.4 percent and ranges from 2.3 percent to 2.7 percent. Conditions in the downstream reach were characterized by BFW measurements in three places (see Section 2.7.2), which have an average BFW of 9.2 feet. Sediment distribution was measured from two pebble counts, one taken inside, and one taken outside of the reference reach, upstream and downstream of the culvert as discussed in Sections 2.7.3. By measuring from edge to edge on the extents of the surveyed channel meanders, the meander belt width of the downstream reach was measured to be from 20 feet to 25 feet based on survey and LiDAR data that shows the detailed channel alignment.

Concurrence on the location of the reference reach by WDFW and the Suquamish Tribe was obtained during a site visit on February 3, 2022. WDFW and the Suquamish Tribe provided direction to include BFW measurements taken from locations both upstream and downstream of the culvert given the transition from the slightly steeper upstream reach to the flatter downstream reach.

2.7.2 Channel Geometry

The roadway and culvert are located at an inflection point in the longitudinal stream profile where the stream transitions from a steeper and confined reach as shown in Section 2.7.4, where it has down cut into the hillslope to a reach with a narrow alluvial flat that has wider overbank areas. The longitudinal slope ranges from up to 3.5 percent upstream of the culvert, which has a meandering pool-riffle morphology with moderate sinuosity channel planform, to 2.3 percent downstream of the culvert, which has a plane-bed morphology. The reference reach has a slope of 2.7 percent. Immediately upstream of the crossing, the stream has a flat floodplain that is approximately 70 feet wide at its widest point. Outside of this area, the channel is confined and minimal floodplain is available. The bankfull depth upstream of the crossing ranges from approximately 1.0 foot to 2.0 feet and widths range from 7.0 feet to 8.0 feet, resulting in a width-to-depth ratio of approximately 5.0. The bank side slopes range from 3:1 to 2:1 and generally consist of fine sediment mixed with cobbles covered by ferns and native shrubs. The upstream reach resembles the Stage 3 - Degradation phase in the channel evolution diagram of *Providing Aquatic Organism Passage in Vertically Unstable Streams (Castro et al. 2016)*. Downstream of the crossing, the bankfull depths range from approximately

0.5 foot to 2.0 feet, and widths range from 8.5 feet to 10.5 feet, resulting in a width-to-depth ratio of approximately 7.5. The bank side slopes downstream of the crossing range from 3:1 to 2:1 and generally consist of fine sediment mixed with cobbles, covered by ferns and native shrubs. The downstream reach resembles Stage 5 – Aggradation and Widening of the channel evolution diagram *(Castro et al. 2016)*.

Three BFWs were measured upstream of the crossing and five BFWs were measured downstream of the culvert (see Figure 6). See Figure 23 through Figure 27 for photos of select BFW measurements. Three of the downstream BFWs were taken in the reference reach (see Figure 6). The top of bank was identified by an inflection point in the slope. At the time of the measurement, the water depth was approximately 6 inches to 12 inches.

Figure 24: BFW8 of 7.6 feet, taken approximately 235 feet upstream of crossing, looking perpendicular to stream

Figure 25: BFW5 of 8.5 feet, taken approximately 80 feet downstream of the crossing (photo has minor corruption issue, and no other photos are available), looking upstream

Figure 26: BFW3 of 8.5 feet, taken approximately 250 feet downstream of crossing, looking downstream

Figure 27: BFW1 of 9.3 feet, taken approximately 350 feet downstream of crossing, looking downstream

Table 3 summarizes the BFWs, which range between 7 feet and 10.5 feet. The BFW of the measurements selected for design have an average of 9.2 feet. BFW measurements 6, 7, and 8 were not included in the design average because they are located upstream of the crossing in the area influenced by the historical landslide thought to have altered the natural conditions of the stream. The measured BFWs and hydraulic opening were discussed with WDFW staff and Suquamish Tribal representatives, and a final conservative BFW rounding up to 10.0 feet was agreed upon during Site Visit 3 on February 3, 2022. This is similar to the average BFW of the reference reach which is 8.9 feet. This BFW of 10.0 feet will be used to inform the design channel width, the depth of the channel based on representative width-to-depth ratios (7.5), and the minimum hydraulic opening (see Section 4.2). The width-to-depth ratio of the upstream reach impacted by the historical landslide will not be considered for design for the same reasons as the disregarded upstream BFW measurements. Figure 28 shows the five BFWs selected for the design average. BFW3, BFW4, and BFW5 are all within the reference reach and are consistent with the other BFW measurements.

Table 3: Bankfull width measurements

BFW number	Width (ft)	Included in design average?	Location measured (distance from culvert)	Concurrence notes
1	9.3	Yes	350 feet downstream	Stakeholder added on 2/3/2022
2	9.0	Yes	300 feet downstream	Stakeholder added on 2/3/2022
3	8.5	Yes	250 feet downstream	Stakeholder added on 2/3/2022
4	10.5	Yes	185 feet downstream	Stakeholder concurred on 2/3/2022
5	8.5	Yes	80 feet downstream	Stakeholder concurred on 2/3/2022
6	8.0	No	120 feet upstream	Stakeholder concurred on 2/3/2022
7	7.0	No	165 feet upstream	Stakeholder added on 2/3/2022
8	7.6	No	235 feet upstream	Stakeholder added on 2/3/2022
Design average	9.2			Design BFW of 10.0 feet agreed upon on 2/3/2022

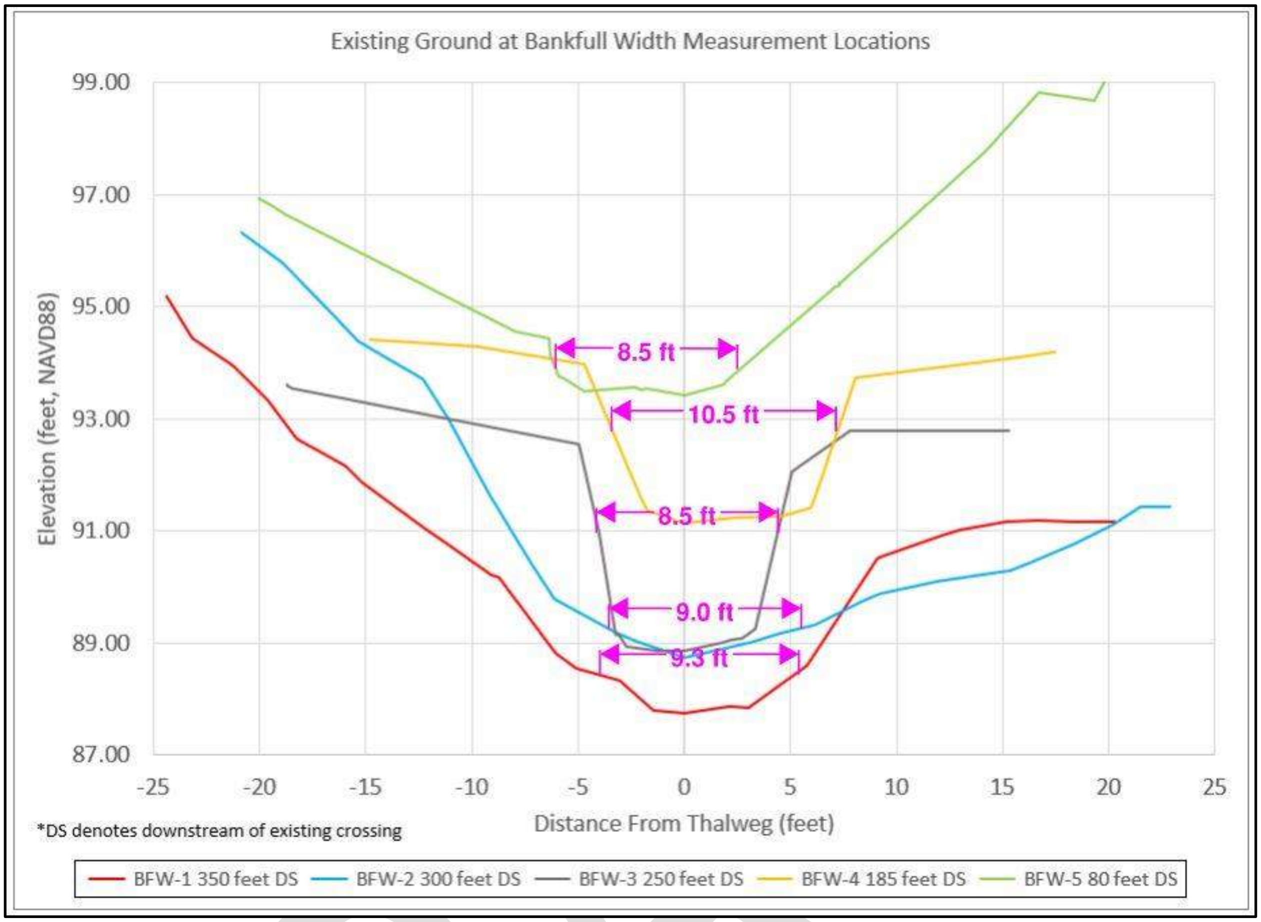

Figure 28: Existing cross sections at five BFW locations within the reference reach

2.7.2.1 Floodplain Utilization Ratio

The floodplain utilization ratio (FUR) is a ratio of the flood-prone width (FPW) to the BFW. The FPW of Little Scandia Creek was determined by measuring the 100-year flood width from the existing conditions hydraulic model at various representative locations upstream and downstream of the crossing. Figure 29 shows the location of each FPW measurement, and Table 4 provides the FPW measurements and FUR values. The upstream FPW measurements were taken outside the backwater conditions of the existing crossing. The FUR varies from 1.0 to 2.8. The upstream average FUR is 1.9. The average FUR within the reference reach is 2.2, and the average of all the downstream FUR measurements, including those within the reference reach, is 1.9. The average of all FUR measurements excluding the FUR measurement 130 feet upstream due to channel impacts from the historical landslide is 2.1, which indicates that this channel is confined.

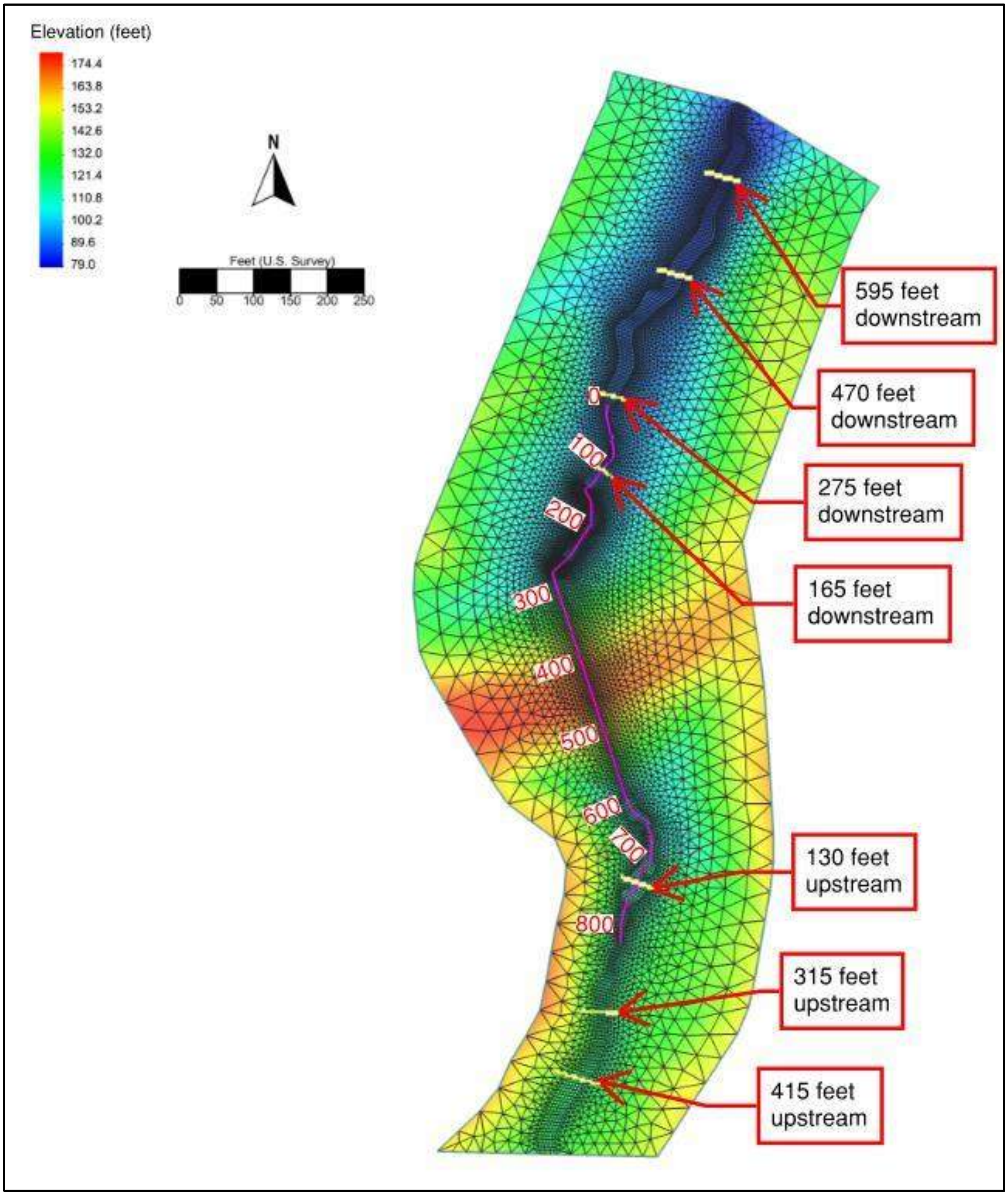

Figure 29: FUR locations

Table 4: FUR determination

Location	FPW (ft)	FUR	Confined/unconfined	Included in average FUR determination
415 feet upstream	19.1	1.9	Confined	Yes
315 feet upstream	27.8	2.8	Confined	Yes
130 feet upstream	9.6	1.0	Confined	No
165 feet downstream (reference reach)	19.6	2.0	Confined	Yes
275 feet downstream (reference reach)	24.2	2.4	Confined	Yes
470 feet downstream	13.9	1.4	Confined	Yes
595 feet downstream	18.7	1.9	Confined	Yes
Average	**20.6**	**2.1**	Confined	Yes

2.7.3 Sediment

DEA conducted three Wolman Pebble Counts (PCs) at the site—one in the reference reach and two outside of the reference reach. See Figure 6 for pebble count locations. PC2 was not included in the sediment analysis, because it was determined to be within the limits of backwater conditions from the existing culvert during high flow events. It is possible that the system has not recently experienced a high flow event causing backwater and altering the sediment upstream of the culvert, but PC2 will not be considered in the design average as a conservative measure. The channel bed is dominated by coarse material ranging from fine gravels to cobbles. One step-forming boulder was observed upstream of the crossing, but the pebble counts did not observe other instances of boulders, bedrock, or armoring layers. The geotechnical scoping memo provided by WSDOT on September 7th, 2022 contained three soil borings, up to 72 feet deep, along the existing culvert alignment that support the lack of boulders, bedrock, and armoring layers observed during the pebble counts.

The fine gravel and cobble materials present in the system create a low-amplitude pool-riffle sequence where the flow over the riffles is less than 6 inches deep, and the flow through the pools is less than 12 inches deep. Because of the shallow pools, the bed material is relatively consistent throughout the reach, and there is not much channel complexity.

The pebble count within the reference reach (PC1) extended over a distance of approximately 20 feet that exhibited faster flows and few fines; therefore, this pebble count represents the upper size limit of coarse material that could be mobilized by the stream without the influence of woody material or other potential grade controls. In slack water areas such as pools or eddies, this material will become overtopped with sand and silt, as was observed within the reference reach. The significant sand mode, shown in Figure 33, may decrease the mobility of larger bed material by embedding and shielding the larger bed material before it becomes mobile at moderate flows.

PC1 was conducted along a length of stream approximately 90 feet downstream of the culvert outlet, inside of the reference reach. The size distribution of PC1 was consistent with the PCs conducted upstream of the culvert. See Figure 30.

Figure 30: PC1 approximately 90 feet downstream of the culvert outlet, inside of the reference reach

PC2 was conducted along a length of stream approximately 46 feet upstream of the existing culvert inlet. The sediment here consisted of coarse sands, gravels, and small cobbles of 3.5 inches or less. This pebble count location was ultimately not considered in the sediment analysis, because it is within the limits of backwater conditions from the existing culvert (see Figure 31).

Figure 31: PC2 approximately 46 feet upstream of the culvert inlet; not included in sediment analysis

PC3 was conducted along a length of stream approximately 99 feet upstream of the existing culvert inlet. The sediment here consisted of coarse sands, gravels, and small cobbles of 5.0 inches or less (see Figure 32).

Figure 32: PC3 approximately 99 feet upstream of inlet; outside of the reference reach

Table 5: Sediment properties near the project crossing

Particle size	PC1 diameter (in)	PC2 diameter[a] (in)	PC3 diameter (in)	Average diameter for design (in)
Included in average?	Yes	No	Yes	
$\mathbf{D_{16}}$	0.18	0.004	0.004	0.09
$\mathbf{D_{50}}$	0.67	0.53	0.70	0.69
$\mathbf{D_{84}}$	1.48	1.69	1.48	1.48
$\mathbf{D_{95}}$	2.30	2.72	2.07	2.19
$\mathbf{D_{100}}$	5.04	5.04	3.54	4.29

[a] PC not included in design average.

Figure 33 shows the sediment size occurrence and cumulative percent finer for each of the three pebble counts.

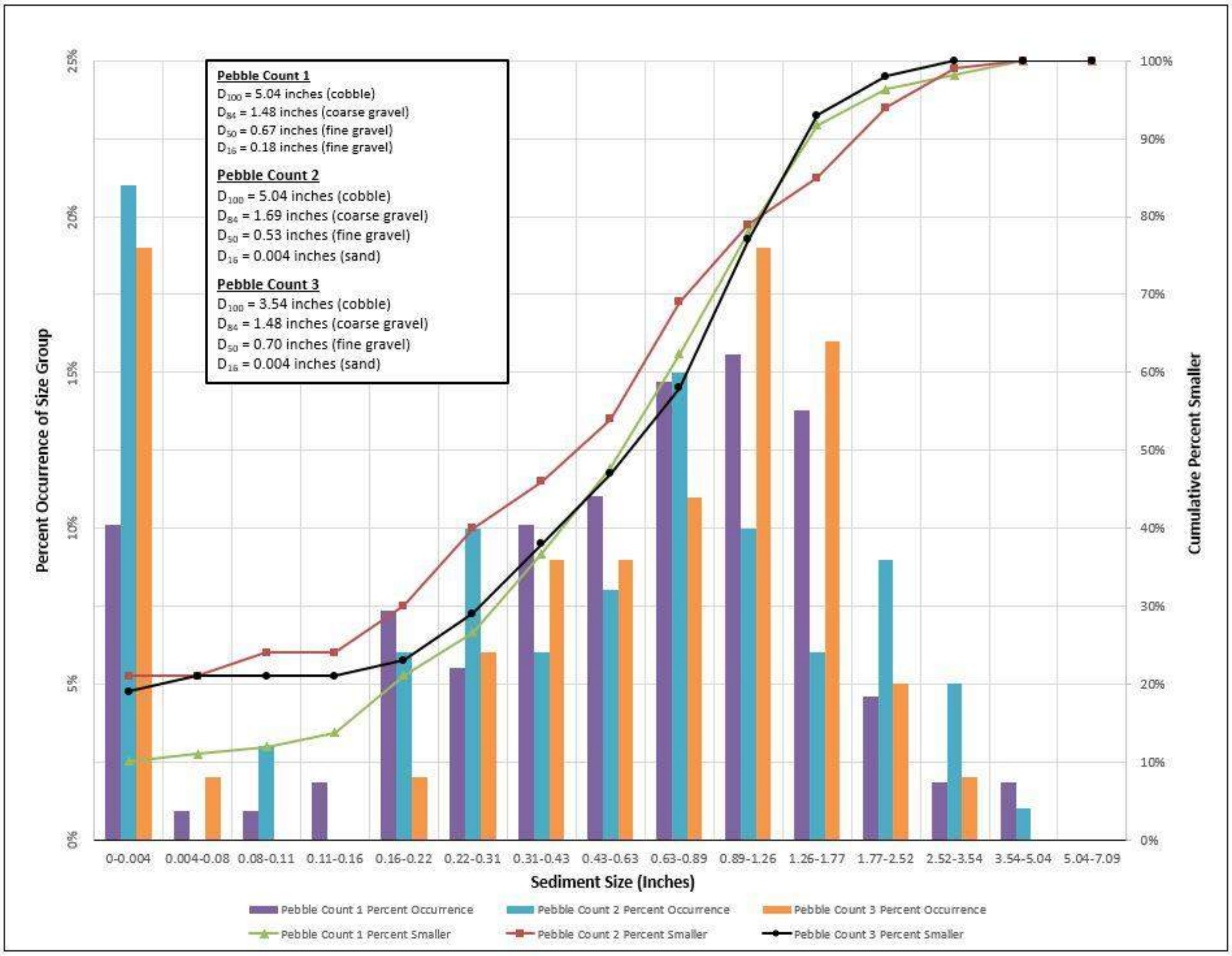

Figure 33: Sediment size distribution

2.7.4 Vertical Channel Stability

The upstream portion of Little Scandia Creek appears to have ample sediment supply, because there is no evidence of recent erosion in the form of downcutting or lateral migration indicating that the channel is vertically and laterally stable. There are locations that are influenced by large wood or trees (see Figure 11) that have locally created greater channel complexity in the form of deeper pools, sand deposition, and bank undercutting. Increasing the amount of woody material in the channel will improve habitat but is not necessary for channel stability. Upstream of the culvert a small step and plunge pool are formed by an underlying boulder that cause aggradation in the bed upstream of the boulder (see Figure 34).

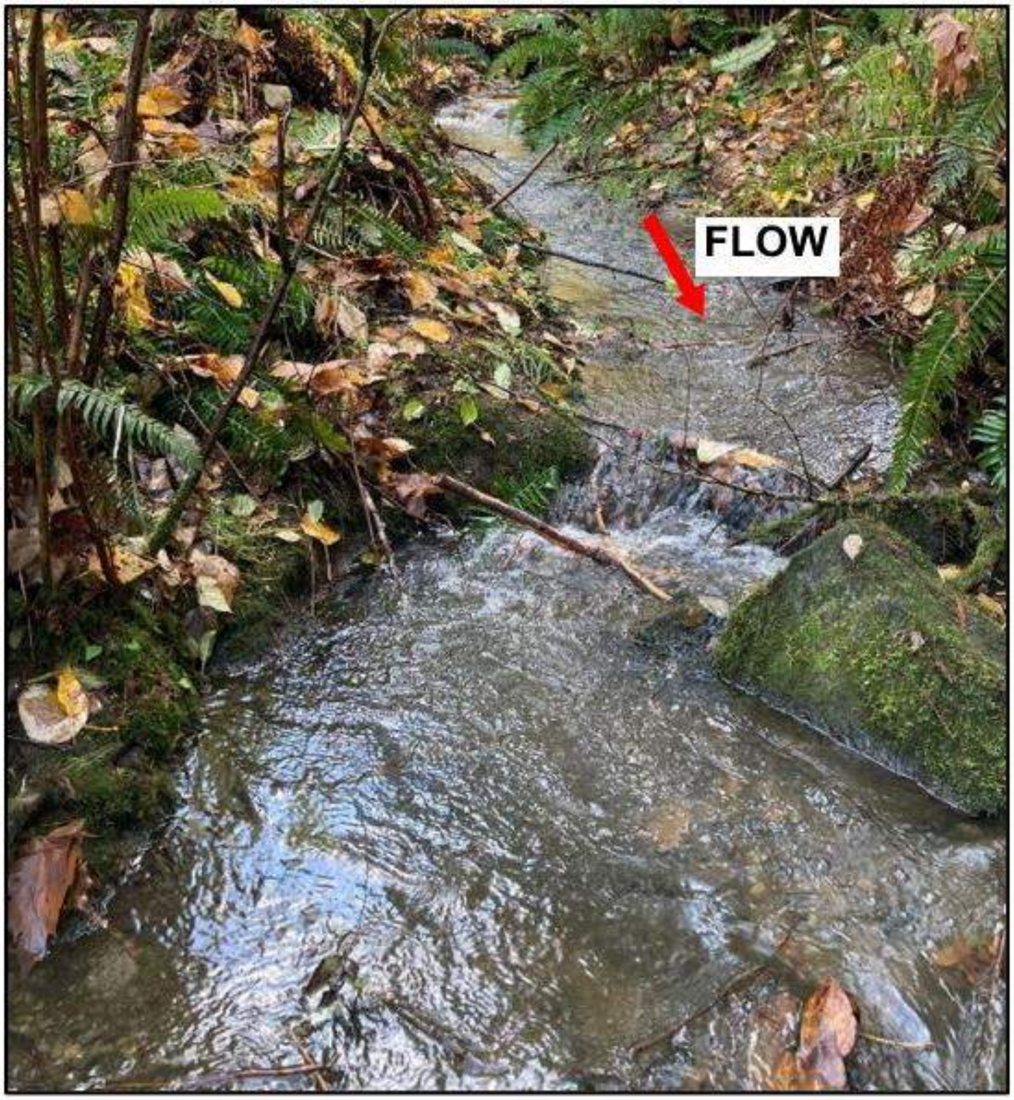

Figure 34: Typical stream characteristic with small step formed by boulder, looking upstream

Modeling of the existing conditions (see Appendix H) indicates that the existing crossing creates a backwater condition upstream of the crossing. Although no measurable aggradation was observed within the limits of the modeled backwater, the pebble count and sediment observations in this area will not be used to inform the proposed design as the backwater may cause a change in the sediment distribution. This lack of aggradation likely indicates that the existing crossing does not significantly limit sediment supply to the channel downstream of the crossing, though the reach immediately downstream of the culvert for about 100 feet appeared to be incised by 1 foot to 2 feet. There was also evidence of erosion in the form of channel incision at the culvert outlet, undercut banks, and recent tree falls (see Figure 35), which could have been caused by elevated velocities at the outlet of the culvert. The degradation and steps described here are visible on the longitudinal profile of the stream survey (see Figure 36). The geomorphic equilibrium channel slope in the vicinity of the SR 308 crossing is 1.7 percent. The equilibrium slope was constructed by extending the downstream slope to a very dense degradation resistive soil unit identified in the geotechnical scoping memo for this site. The long-term degradation is potentially up to 7 feet at the upstream structure face (see Figure 36). Refer to Section 7.2 for further discussion on the potential long-term degradation. The current crossing is acting as a grade control structure, and the 1 to 2 feet of incision noticed downstream of the culvert resembles what is predicted by the equilibrium slope in Figure 36.

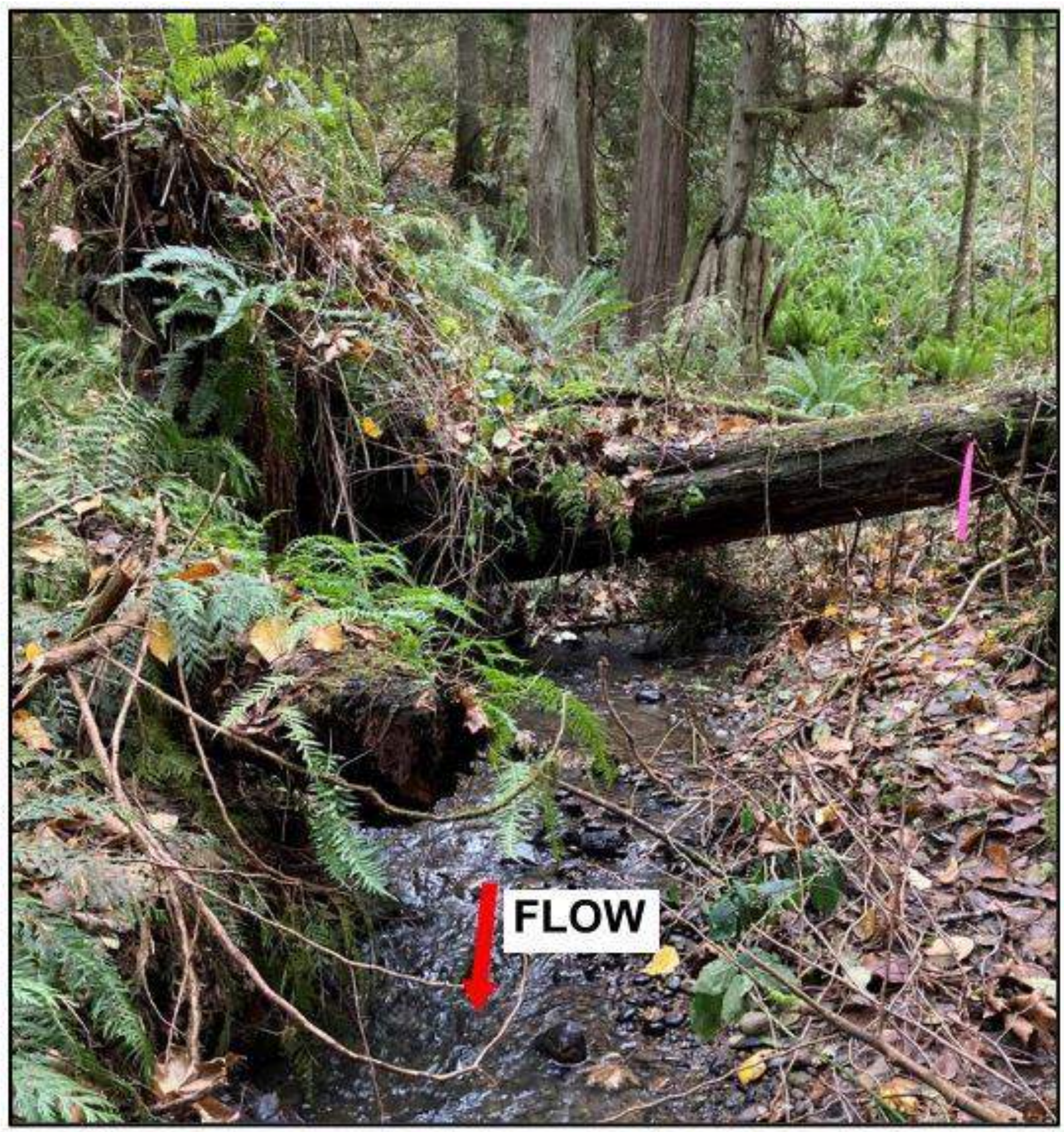

Figure 35: Tree fall potentially caused by root undercutting and channel incision downstream of culvert, looking upstream

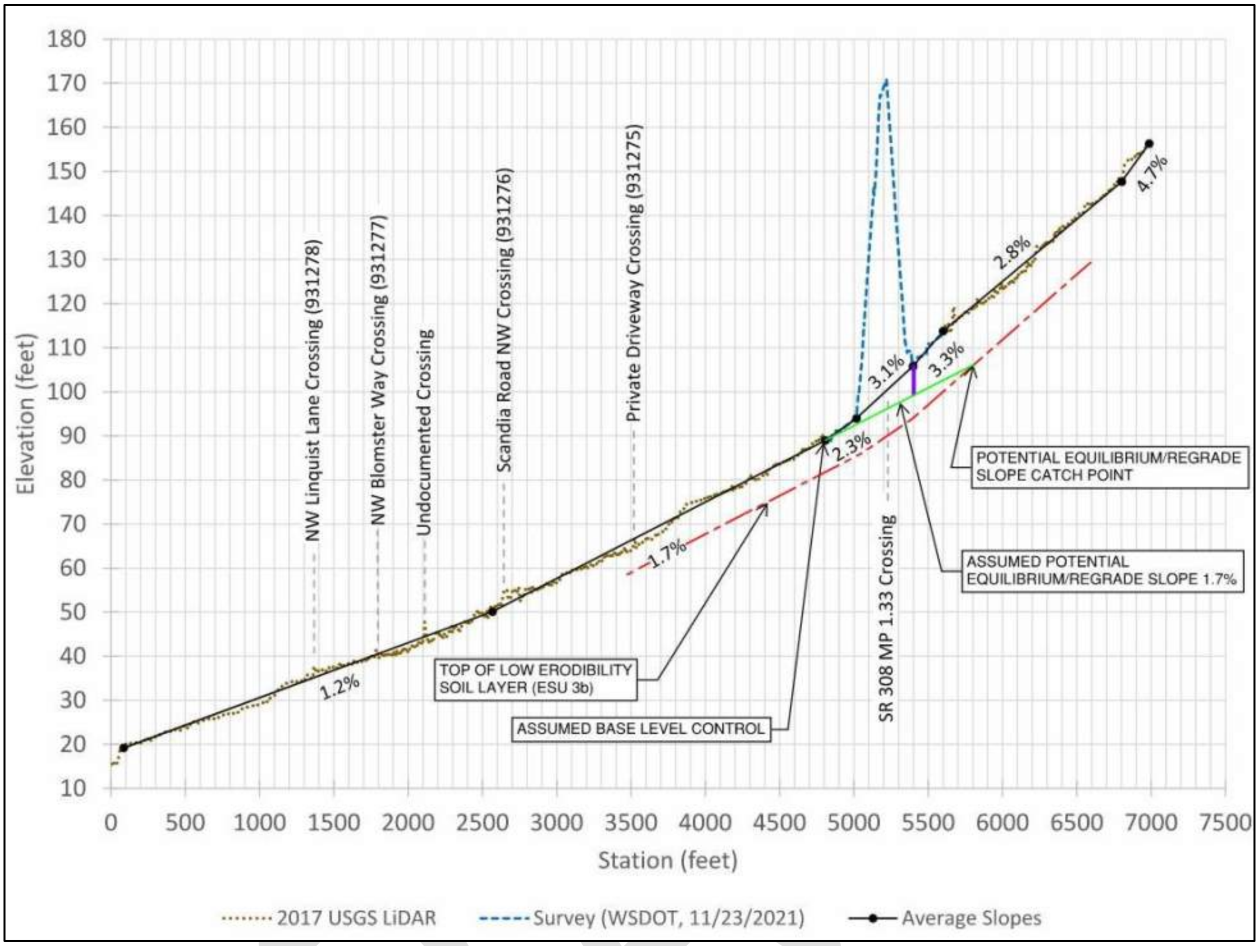

Figure 36: Watershed-scale longitudinal profile

The channel takes a sharp bend at the culvert outlet, and there is angular rock scour protection present in the channel and a rock wall on the left side of the culvert outlet to support the slope and reinforce the bend (see Figure 17). Downstream of the rock scour protection, there is evidence of some minor aggradation as the stream transitions to a shallower slope. However, this area of minor aggradation is followed by an area with minor incision and erosion, which may be the result of channel adjustment to a shorter alignment and steeper slope. Downstream of this incised portion of the stream, the channel has little incision and less evidence of bank erosion (see Figure 28).

Several instances of natural grade control exist upstream of the crossing. There is a large, buried boulder near station 6+15 (see Figure 34) that provides some grade control; however, with the proposed realignment of the crossing, this feature will not be present in the proposed stream alignment. The root systems of three trees along the channel alignment near station 6+30 (see Figure 11) provide semi-stable grade control. A third natural grade control is present in the stream near station 7+20 (see Figure 9) in the form of two trees within the channel. Although these trees did not show signs of undermining, the accumulated debris upstream of the trees appeared instable and transitory. As the stream undermines the trees at station 6+30 and station 7+20, the form and stability of the grade control will evolve in unpredictable ways. Instances of channel spanning LWM downstream of the crossing (see Figure 35) are above the channel limits and do not provide grade control. Over time the LWM could shift into the channel and provide grade control at these locations.

2.7.5 Channel Migration

The site visits revealed no evidence of recent lateral erosion or migration, nor did site visits or LiDAR topography show any longer-term channel migration. A review of the LiDAR topography and geologic mapping (Figure 4) indicate that a historical landslide of indeterminate age may have shifted the creek alignment to the left, away from the center of the ravine. The road embankment and culvert installation likely realigned, shortened, and steepened the channel, which may explain the steepness of the culvert and the observed incision for about 100 feet downstream of the culvert. Downstream of the culvert, the channel is in a wider but still confined alluvial flat that was likely formed by previous channel deposition, although no archival channels were observed.

Throughout the reference reach and the area impacted by the historical landslide, the channel is confined by the valley hillslopes and there is limited to no floodplain. The meander belt width in the downstream reference reach is approximately 20 feet to 25 feet. The downstream channel is not expected to expand its floodplain and appears to be laterally stable. A low risk of channel migration exists through this section of the stream. The area just upstream of the crossing is unconfined and does have a relatively wide, flat floodplain possibly caused by long term aggradation. Given the short length of this section, from approximately station 6+00 to station 7+20, it is difficult to draw any conclusions about the sinuosity of this section as it is not a natural reach. The stream alignment is along the left side of the floodplain, likely due to the historical landslide, and there is risk of lateral channel migration. To account for this potential, the proposed design shifts the alignment of the proposed crossing to be more centered within the floodplain (see Section 4.1.2). The stream is eroding the toe of the left valley wall which may cause a slope failure of the left valley wall, once again causing the channel to laterally migrate.

3 Hydrology and Peak Flow Estimates

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. The largest risk to bridges and buried structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the projected 2080 percent increase throughout the design of the structure. Appendix G contains the projected increase information for a watershed adjacent to the project site, since the WDFW Climate-Adapted Culvert Design program cannot generate a watershed for the project site. The selected watershed is south of the project site. The design flow for the crossing is 82.1 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2080 100-year flow in the adjacent watershed is 54.7 percent, yielding a projected 2080 100-year flow of 127.0 cfs for the project site.

There are no streamflow gages located on Little Scandia Creek and no stream gages on similarly sized streams nearby. The USGS web app StreamStats (USGS 2016) does not provide accurate basin delineation at this location, because the mapped streamlines within StreamStats for this small stream are not representative of the actual channel location. The stream has a summer low flow, and therefore does not dry up.

It is assumed that peak flows from Little Scandia Creek's subbasin are the only flows affecting the crossing at Site 992008. No other sources of significant flow, including the 100-year flood (FEMA 2017), encroach upon the SR 308 roadway at this location.

Peak flows were evaluated at regular return intervals using two methods: the USGS regression equations for Region 3 and MGSFlood software. Table 6 shows the results from each method. The USGS flows are less than half of the MGSFlood flows which may be due to the USGS regression equations not accounting for a level of development like the watershed of Little Scandia Creek. To determine which data set is more appropriate for this channel, the 2-year flows from each data set were tested in the hydraulic model. The extents of the 2-year peak flow from the MGSFlood model were more in line with the field-measured bankfull widths than the flows from the USGS regression equations. The depth at the outlet was closer to the height of the rust line measured from site photos to be 1 foot. Therefore, the MGSFlood flows were selected as the best approximation of typical flows for this channel. Other indicators of appropriate flows such as scour lines, high flow debris, or conversations with adjacent landowners were not available to help determine appropriate flows in the channel. Precise accuracy of the peak flows is not quantifiable as the parameters used to develop them are based on broad data sets with various levels of accuracy such as soil type, land cover usage, LiDAR topography, and agreed upon bankfull width measurements in the field.

Table 6: Peak flows for Little Scandia Creek at SR 308

Mean recurrence interval (MRI) (years)	USGS regression equation (Region 3) (cfs)	MGSFlood (cfs)
2	6.6	**25.1**
10	13.4	**48.2**
25	16.9	**60.1**
50	19.5	**65.5**
100	22.4	**82.1**
500	29.1	**144.3**
Projected 2080 100	34.6	**127.0**

4 Water Crossing Design

This section describes the water crossing design developed for SR 308 MP 1.33 Little Scandia Creek, including channel design, minimum hydraulic opening, and streambed design.

4.1 Channel Design

This section describes the channel design developed for Little Scandia Creek at SR 308 MP 1.33.

The proposed design utilizes one typical cross section shape that is implemented over 450 feet of channel grading (Figure 37). The proposed grading follows a straight alignment that relocates the existing crossing about 16.8 feet east of the existing inlet and 37.9 feet east of the existing outlet (see Section 4.1.2 for more detail). The proposed grade of the crossing is at a constant 3.2 percent. Variability in cross sectional shape, vertical, and horizontal alignment was not warranted as the flows and adjacent slopes were consistent throughout the project area. Minimizing grading impacts to the downstream reach, as preferred by co-managers, also contributed to the proposed channel design. Meander bars and a low flow channel will add to the complexity of the proposed pool riffle stream along a straight alignment at a constant grade.

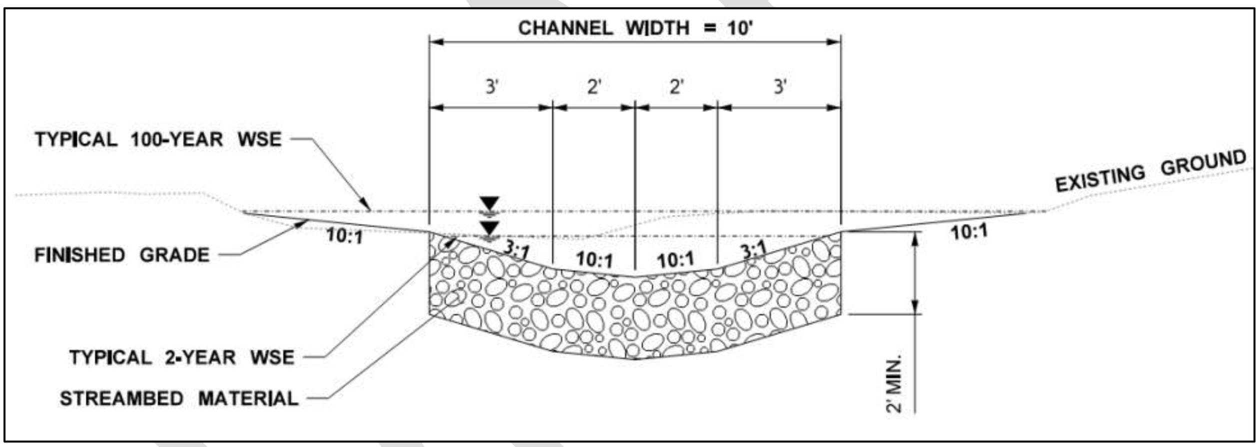

Figure 37: Design cross section

4.1.1 Channel Planform and Shape

The WCDG (Barnard et al. 2013) recommends that a proposed stream channel have a gradient, cross section, and general configuration that is similar to the existing channel upstream and downstream of the proposed crossing, provided that the adjacent channel has not been modified in a way that adversely affects natural stream processes. The stream assessment evaluated existing conditions for Little Scandia Creek upstream and downstream of the SR 308 crossing. Due to the co-managers selecting a reference reach in an area much flatter than what the gradient of the proposed crossing could be constructed as well as the reference reach lacking floodplain benches to accommodate the minimum hydraulic opening as shown in Figure 38, the width to depth ratios of the reference reach are much smaller than the proposed crossing which has faster velocities, shallower depths, and a wider water surface width. The average width to depth ratio at station 0+56 in the reference reach for all the proposed flows (2-

year, 100-year, 2080 100-year, and 500-year events) is 7.7 while the average width to depth ratio at station 1+07 in the reference reach is 4.9 across the same flow events. The average width to depth ratio through the proposed structure at station 4+00 is 10.2.

Much of the channel hydraulic properties, such as flow depth, velocities, and sediment transport, depend on the shape of the channel cross section. Therefore, the proposed channel shape is designed to mimic the existing sections observed in the reference reach and measured from survey data. Figure 38 shows a typical section of the proposed channel geometry and compares it to cross sections of the existing channel, both upstream and downstream of the SR 308 crossing as well as within the reference reach. Observed channel banks at the project site were relatively stable and did not have much erosion at the reference reach, so these bank slopes were used to determine the proposed channel cross section bank slopes. In general, mimicking the existing channel shape in determining the proposed design will support creation of flow regimes at the proposed section that will continue the same channel processes seen in the reference reach and through the crossing. The cross-slope of the proposed channel bed was also estimated using the reference reach channel shape to ensure that sediment transport remains steady and representative of the existing reference reach. Using the channel shape of the reference reach to estimate the proposed channel bed cross-slope also ensures that the proposed channel section will not have degradation or aggradation of sediments on the bed. Designing the proposed channel section based on bank heights and widths from the reference reach means that flow depths and velocities for fish passage and habitat will be close to natural conditions during low or high flows. A channel that is too wide can result in lower flow depth during low-flow periods, and narrow sections can result in higher velocities than those of the natural conditions of the channel, which would in turn adversely affect fish passage and habitat. The channel is intended to provide adequate depth and flow velocities, so that salmonids can use it across all their life stages.

The proposed channel width is 10 feet, which consists of a 4-foot channel bottom with 3:1 bank slopes that extend 3 horizontal feet on each side of the channel bottom. The proposed design has channel benches on both sides of the channel (4.5-foot horizontal width at 10 percent grade) before the typical cross section resumes the 2:1 grade to tie into the existing ground. The proposed channel depth is 1.2 feet. The 2-year water surface elevation approximately fills up the channel reaching within 0.1 feet of the floodplain benches as shown in Figure 37. Further hydrologic analysis is warranted in the final design phase to confirm appropriateness of channel size relative to the modeled 2-year flows.

The modeled 2-year water surface width in the proposed conditions is approximately 9 feet throughout the crossing and in adjacent sections of stream, whereas the BFW measurements taken varied from 7.0 feet to 10.5 feet. In later stages of the project, a low-flow channel will be added that connects habitat features together so that the project is not a low-flow barrier. The low-flow channel will be as directed by the engineer in the field. The meander belt width assessment showed the meander belt of the stream to be about 20 to 25 feet in width as described in Section 2.7.1.

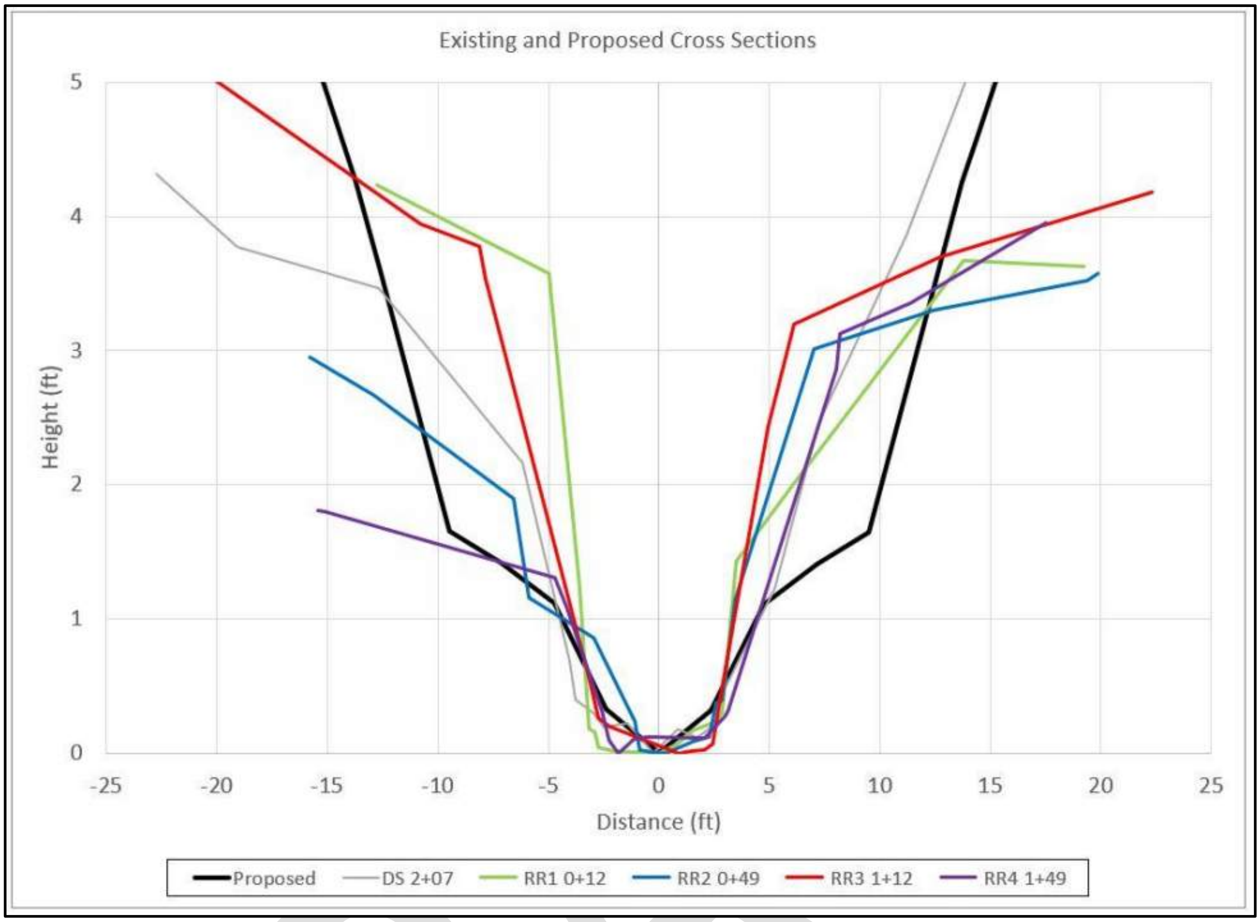

Figure 38: Proposed cross section superimposed with existing survey cross sections looking downstream

The proposed cross section in Figure 38 was developed from blending the four reference reach (referred to as "RR" in the figure) cross sections together. The proposed cross section matches the reference reach existing cross sections in the main channel for depth and width but is generally wider in the floodplain bench areas to achieve the desired minimum hydraulic opening. An additional cross section is shown from immediately downstream of the SR 308 crossing (DS 2+07).

4.1.2 Channel Alignment

The existing culvert crosses SR 308 at a perpendicular angle. It is believed that a historical landslide pushed the channel to the west on the upstream side of the crossing before the installation of the culvert and roadway fill. For these reasons, the crossing alignment is proposed to be relocated about 16.8 feet east of the existing inlet and 37.9 feet east of the existing outlet, creating a slight skew of approximately 9 degrees from a perpendicular crossing of SR 308. This realignment will mimic the natural alignment of the crossing. The proposed design will not include sinuosity, but meander bars and a low flow channel will be added to provide channel complexity through the proposed crossing. See the project plan sheets in Appendix D.

4.1.3 Channel Gradient

The upstream channel tie-in point is proposed at station 6+50, which is roughly 44 feet upstream of the existing SR 308 culvert. The downstream tie-in point is proposed at station 2+00, which is roughly 70 feet downstream of the existing SR 308 culvert. These tie-in locations avoid unusually high or low points in the existing thalweg and mimic as closely as possible the adjacent stream grades. See the proposed profile in Appendix D.

The WCDG recommends that the proposed stream channel gradient be no more than 25 percent steeper than the upstream channel gradient, meaning that the ratio of proposed channel slope to upstream channel slope is less than 1.25 (WCDG Equation 3.1). The slope of the proposed channel between proposed tie-in points is 3.2 percent. The existing slope upstream of the tie-in point is about 3.0 percent, which results in a slope ratio of 1.07.

The channel slope immediately downstream of the crossing is approximately 2.4 percent, while the greater watershed downstream of the crossing has a slope of 1.8 percent. The channel may experience long-term degradation as the channel naturally finds an equilibrium between the flatter slope of the downstream channel and the steeper proposed channel slope of 3.2 percent. The potential for long-term degradation is discussed in Sections 2.7.4 and 7.2.

4.2 Minimum Hydraulic Opening

The minimum hydraulic opening is defined horizontally by the hydraulic width and the total height is determined by vertical clearance and scour elevation. This section describes the minimum hydraulic width and vertical clearance; for discussion on the scour elevation see Section 7. See Figure 39 for an illustration of the minimum hydraulic opening, hydraulic width, freeboard, and maintenance clearance terminology.

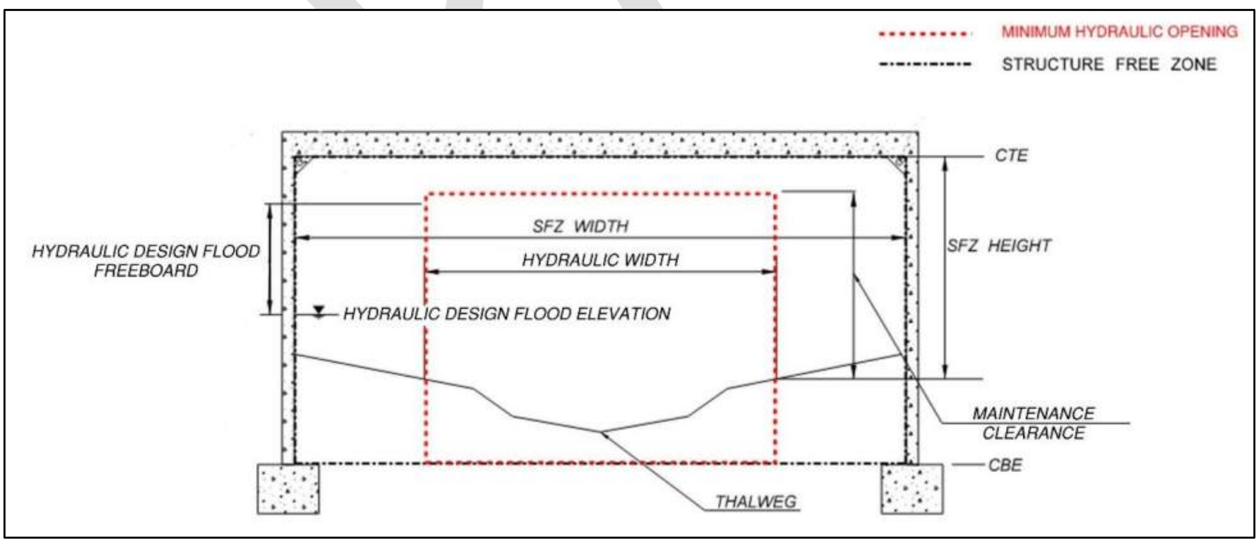

Figure 39: Minimum hydraulic opening illustration

4.2.1 Design Methodology

The proposed fish passage design was developed using the WCDG (Barnard et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2022a). Using the guidance in these two documents, the stream simulation design method was determined to be the most appropriate at this crossing because the BFW is less than 15 feet (see Section 2.7.1 and Section 2.7.2), the FUR calculations show the channel is moderately confined (Section 2.7.2.1), and the slope ratio is less than 1.25 (Section 4.1.3). The stream simulation design method is also appropriate because very little or no lateral movement is expected and moderate vertical channel movement is anticipated (see Section 2.7.4, Section 2.7.5, and Section 7.2). The length of the crossing to evaluate whether the stream simulation culvert is considered “long” by WCDG standards is contained in Section 4.2.4. The footprint of the fill and climate resilience of the proposed crossing will be accommodated by selecting a proper structure type in later design phases (see Section 4.2.6) and by analyzing the 2080 projected 100-year flow event (see Section 5).

4.2.2 Hydraulic Width

The starting point for the minimum hydraulic width determination of all WSDOT crossings is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic width of 14 feet was determined to be the minimum starting point. For the stream simulation design methodology, the WCDG recommends sizing the span of a proposed structured based on the agreed-upon BFW, with the span being the greater of *1.2 x BFW + 2 feet* (WCDG Equation 3.2) or *1.3 x BFW* (Hydraulics Manual Equation 7-2). For Little Scandia Creek agreed-upon BFW of 10.0 feet, Equation 3.2 results in a minimum hydraulic opening of 14.0 feet, and Equation 7-2 results in a minimum hydraulic opening of 13.0 feet. A minimum hydraulic opening used in the design is 14.0 feet, which is conservative choice over 13 feet and better meets the desires of co-managers.

The WCDG also recommends in some cases to increase the minimum hydraulic opening due to excessive backwater, velocity differences between the crossing and the adjacent undisturbed reach, expected channel migration, or natural sinuosity of the channel, or if the proposed structure is considered a long crossing. Long crossings are defined as any crossings where the ratio of the crossing length to the minimum hydraulic opening exceeds 10. The length of the proposed SR 308 crossing is approximately 296 feet, which results in a length-to-width ratio of 21.1. The SR 308 crossing is thus considered a long crossing. The WCDG recommends increasing the minimum hydraulic opening width by 30 percent for long crossings. For the SR 308 crossing, this recommendation results in a minimum hydraulic opening of 18.2 feet, or 19 feet (rounded up to the nearest whole foot).

Although the proposed crossing does not create excessive backwater or significant differences in velocities, natural sinuosity of the channel through the reference reach was apparent during the meander belt width assessment (see Section 2.7.1). The downstream section of the channel has a slope of approximately 2.4 percent and a meander belt width of 20 feet to 25 feet during the 100-year event, based on modeling results. The proposed crossing has a slope of 3.2 percent, which is slightly steeper than the reference reach. In general flatter stream profiles result in wider meander belts; therefore, any meanders that form through the crossing are expected to be less than the 20 feet to 25 feet in the reference reach. The section of Little Scandia Creek upstream of the crossing has a slope of approximately 3.0 percent, which more closely matches the proposed slope of the crossing, but the channel alignment has been impacted by a historical landslide such that the meander belt width does not appear to be representative of an unimpacted stream. As such, the 19-foot minimum hydraulic opening, which includes the 30 percent increase as a safety factor, is expected to provide sufficient width for the channel to form some natural sinuosity consistent with its slope. Future design efforts should verify the roadway design requirements and forward compatibility needs at the time of design. These can impact the length of the crossing and potentially the minimum hydraulic opening.

The first iteration of design modeled a minimum hydraulic width of 19 feet, which allows for sufficient conveyance of the design flow events based on the hydrology described in Section 3 and for natural sinuosity to form within the crossing mimicking the present geomorphology noted during the site visits. The modeled results for existing and proposed conditions are contained in Section 5.2 and Section 5.4 respectively. The modeling did not conduct further iterations of hydraulic width to analyze velocities. A factor of safety in minimum hydraulic opening sizing was achieved through conservative instances of rounding up. As stated in Section 2.7.1 the design BFW used to determine the minimum hydraulic opening was rounded up from 9.2 feet to 10 feet. If 9.2 feet was used to determine minimum hydraulic opening utilizing WCDG Equation 3.2 and the 30 percent increase due to the crossing being considered “long”, the minimum hydraulic opening would have been 17 feet instead of 19 feet. The conservative increase of 2 feet in minimum hydraulic opening represents about a 12 percent increase in hydraulic width.

Based on the factors described above, a minimum hydraulic width of 19 feet was determined to be necessary to allow for natural processes to occur under current flow conditions. The projected 2080 100-year flow event was evaluated. Table 7 compares the velocities of the 100-year and projected 2080 100-year events.

Table 7: Velocity comparison for 19-foot structure

Location	100-year velocity (ft/s)	Projected 2080 100-year velocity (ft/s)	Percent Increase in velocity (%)
Reference reach (STA 0+56)	6.4	7.3	13.4
Upstream of structure (STA 6+08)	4.4	5.0	12.3
Through structure (STA 4+00)	6.1	7.0	15.4
Downstream of structure (STA 2+07)	4.9	5.6	13.2

Projected 2080 100-year velocities are approximately 13.6 percent higher than the proposed 100-year velocities. A 19-foot minimum hydraulic opening allows for a proposed channel similar in shape to the reference reach (see Section 4.1.1) to convey and contain flow events similarly to the reference reach and provide space for lateral channel migration. The increase in velocities through the structure shown in Table 7 is primarily due to the crossing being steeper than the adjacent reaches of stream as well as the reference reach to meet requests of the co-managers such as limiting habitat disturbance instead of aiming for a ratio of slopes equal to 1.0. The proximity of the select cross sections to existing pools may also influence their velocities. Graphical representations in Section 5.4 and Appendix H show how the velocities are consistent through the structure.

No size increase was determined to be necessary to accommodate climate change as adequate freeboard is achieved with the proposed minimum hydraulic opening as described in Section 4.2.3. For detailed hydraulic results see Section 5.4.

4.2.3 Vertical Clearance

The vertical clearance under a structure is made up of two considerations: freeboard and maintenance clearance. Both are discussed below, and results are summarized in Table 8.

The minimum required freeboard at the project location, based on BFW, is two feet above the 100-year water surface elevation (WSE) (Barnard et al. 2013, WSDOT 2022a). The WSDOT Hydraulics Manual requires 3 feet of freeboard for all structures greater than 20 feet and on all bridge structures unless otherwise approved by HQ Hydraulics (WSDOT 2022a). The 3-foot freeboard requirement is not expected to apply to this project as the crossing can be accommodated by a box culvert less than 20 feet.

Long-term aggradation and debris risk were also evaluated at this location. Additional freeboard is not required as post-construction aggradation is not expected. More information on the risks for long-term degradation and aggradation can be found in Sections 2.7.4 and 7.2.

WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080 100-year WSE. The WSE is projected to increase by about 0.4 feet for the 2080 projected 100-year flow rate. The minimum required freeboard at this site will be applied above the projected 2080 100-year WSE to accommodate climate resilience.

The second vertical clearance consideration is maintenance clearance. WSDOT HQ Hydraulics determines a required maintenance clearance if a height is required to maintain habitat elements, such as boulders or large woody material (LWM). If there are no habitat elements requiring maintenance clearance to maintain, the maintenance clearance is only a recommendation by WSDOT HQ Hydraulics, and the region determines the maintenance clearance required.

The channel complexity features in Section 4.3.2 do not include elements of significant size other than meander bars containing one-man boulders and will not need to be maintained with machinery. A minimum maintenance clearance of 6 feet is required for maintenance and monitoring purposes but is not a hydraulic requirement. Maintenance clearance is measured from the highest streambed ground elevation within the horizontal limits of the minimum hydraulic width. The 6-foot-maintenance clearance is required by WSDOT HQ Hydraulics for future monitoring and potential repairs due to the length of the proposed structure.

Table 8: Vertical clearance summary

Parameter	Downstream face of structure	Upstream face of structure
Station	2+47	5+43
Thalweg elevation (ft)	95.1	104.6
Highest streambed ground elevation within hydraulic width (ft)	96.7	106.2
100-year WSE (ft)	96.9	106.3
2080 100-year WSE (ft)	97.3	106.6
Required freeboard (ft)	2.0	2.0
Required maintenance clearance (ft)	6	6
Required minimum low chord, 100-year WSE + freeboard (ft)	98.9	108.3
Required minimum low chord, 2080 100-year WSE + freeboard (ft)	99.3	108.6
Required minimum low chord, highest streambed ground elevation within hydraulic width + maintenance clearance (ft)	102.7	112.2
Required minimum low chord (ft)	**102.7**	**112.2**

4.2.3.1 Past Maintenance Records

WSDOT Area 2 Maintenance was contacted to determine whether there are ongoing maintenance problems at the existing structure because of LWM racking at the inlet or sedimentation. The maintenance representative indicated that there was no record of LWM blockage and/or removal or sediment removal at this crossing.

4.2.3.2 Wood and Sediment Supply

The drainage basin for Little Scandia Creek upstream of the crossing is approximately 41 percent forested, and there are no known plans for development or land cover changes in the basin. During site investigations, no LWM was observed upstream of the crossing, and as noted in Section 4.2.3.1, there are no records of maintenance issues at this location. The stream itself is relatively small and has limited ability to move LWM even during the 100-year event (82 cfs). The creek appears to be in equilibrium from a sediment supply perspective; there are only limited signs of aggradation or degradation (see Section 2.3 and Section 2.7.3). The LWM is not expected to influence the sediment supply as stream features such as pools, drops, and roughness from boulders are currently a part of the system that the LWM will enhance (Section 2.6.4).

4.2.4 Hydraulic Length

A minimum hydraulic width of 19 feet is recommended up to a maximum hydraulic length of 296 feet. If the hydraulic length is increased beyond 296 feet, the hydraulic width and vertical clearance will need to be reevaluated. The minimum hydraulic width of 19 feet takes into consideration the WCDG long crossing criteria and geomorphic processes. Preliminary estimates of length at this crossing are 296 feet based on existing fill slopes. Efforts should be made to shorten the length of the crossing to the extent practicable by using a taller structure, headwalls, or wingwalls in later phases of design.

4.2.5 Future Corridor Plans

There are currently no long-term plans to improve SR 308 through this corridor.

4.2.6 Structure Type

No structure type has been recommended by WSDOT HQ Hydraulics. The layout and structure type will be determined at later project phases.

4.3 Streambed Design

This section describes the streambed design developed for Little Scandia Creek at SR 308 MP 1.33.

4.3.1 Bed Material

The development of the proposed streambed mix followed methods recommended in the WCDG for sizing streambed material in culverts and the WSDOT Hydraulics Manual (WSDOT 2022a). The proposed streambed mix design is intended to mimic the average of PC1 and PC3 (see Section 4.3). The streambed material gradation was proportioned to mimic natural conditions to the extent practical using WSDOT standard streambed mixes (WSDOT 2022b). These bed material mixes are well graded materials that include larger less mobile particle sizes as well as smaller, mobile particle sizes to produce a porosity that minimizes the opportunity for flow in the stream to go entirely subsurface during low-flow periods. Silts, sands, and small gravels will comprise the finer portion of the gradation and will fill the interstitial spaces of the larger portions of the gradation.

The proposed streambed material should be constructed utilizing 80 percent Streambed Sediment, WSDOT Standard Specification 9-03.11(1);10 percent 4-inch cobbles; and 10 percent 6-inch cobbles, WSDOT Standard Specification 9-03.11(2). This mix of standard materials matches the existing stream gradation relatively well through the D_{100} (see Table 9). WSDOT Streambed Sediment has the smallest gradation sizes of the standard mixes without the need for a special provision. The minimum allowable streambed depth will be determined based on scour calculations during later design stages.

Table 9: Comparison of observed and proposed streambed material

Sediment size	Observed diameter for design (in)	Proposed diameter (in)	Meander bar head diameter (in)	Meander bar tail diameter (in)
$\mathbf{D_{16}}$	0.1	0.1	0.5	0.4
$\mathbf{D_{50}}$	0.7	0.8	12.0	2.0
$\mathbf{D_{84}}$	1.5	2.0	16.1	5.7
$\mathbf{D_{95}}$	3.3	4.1	17.4	7.3
$\mathbf{D_{100}}$	4.3	6.0	18.0	8.0

The Bathurst method, as recommended by WDFW, is not recommended for use in streams with gradients less than 4 percent (WDFW 2013). The design slope for the proposed Little Scandia Creek to Liberty Bay is 3.2 percent (see Section 5.4). Therefore, the assessment of streambed material did not use the Bathurst method. Instead, the assessment of streambed material used the modified Shields critical shear stress approach, as described in the US Forest Service Stream Simulation guidelines (USDA 2008), to verify whether the proposed sediment sizes are mobile or stable as intended during the full range of design flows. This method compares the critical shear stress for incipient motion for the D_{84} size fraction of the proposed streambed mixture to the average applied shear stress within the proposed grading limits for the 100-year peak flow. The incipient motions for flows other than 100-year peak flows were also checked. These channel stability calculations indicate that D_{50} and D_{84} sediments will be mobile during all modeled flows. Although the calculations show the proposed bed will be mobile, field observations and low flow summer conditions support that the existing bed material sizing is stable. During periods of low flow or dry conditions, the existing bed material becomes compacted adding to its ability to resist motion that the stability calculations do not consider. The proposed bed material will not be adjusted to achieve stability as calculated by the US Forest Service Stream Simulation guidelines, and the proposed bed material will match the existing conditions to the extent practical as previously described. It is recommended in the final design phase that the shear stresses are partitioned to analyze grain size mobility.

Meander bars are recommended at a minimum spacing of 27 feet through the proposed structure and at a width of 6 feet to increase channel bed stability and to mimic the natural sinuosity of the reference reach. The sinuosity of a stream is the ratio of the stream length along the thalweg to the valley length. The reference reach has a sinuosity of 1.12, while the proposed sinuosity through the structure is 1.10. The proposed sinuosity is slightly lower than the reference reach due to the proposed gradient of 3.2 percent and reference slope of 2.4 percent. Streams with higher gradients naturally have lower sinuosity than streams with flatter gradients. The meander bars will also mimic forcing elements typically found in riffle-pool systems to prevent a shift to a plane-bed morphology through the crossing. The design will incorporate meander bars so that a low-flow channel can be introduced with enough complexity to facilitate fish passage through the structure. The meander bars were also designed using the modified Shields critical shear stress approach. The head of the meander bar should consist of about 30 percent Streambed Sediment, WSDOT Standard Specification 9-03.11(1); 20 percent 12-inch cobbles, and 50 percent 12-inch to 18-inch boulders (9-03.11(2)) to be completely stable at the 100-year flow, while the meander bar tail should consist of 33 percent Streambed Sediment, WSDOT Standard Specification 9-03.11(1), and 67 percent 8-inch cobbles WSDOT Standard Specification 9-03.11(2). The height of the proposed meander bar head is approximately equal to the 10-year flow depth which is 1.3 feet. The gradation of the meander bar tail has a D_{50} equal to the D_{84} of the streambed mix in accordance with the WSDOT meander bar guidance and is stable during the 2-year flow event. See Appendix C for results of this analysis. The meander bar head will be reevaluated for stability at later stages of the design when the final structure size, type, and location are known and the hydraulic model is updated.

The coarse proposed bed material, which mimics the observed bed material, helps reduce velocity and increase flow depths. This situation can be helpful for larger fish that can also pass through reference reaches. For juvenile salmonids, the length of the culvert is too long to pass through without added spots where they can rest. To address this issue, the design includes a low-flow channel between meanders, which creates a meandering path that increases complexity by reducing the slope and velocity within the channel. This added complexity helps passage of fish at all stages of life.

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for Little Scandia Creek at SR 308 MP 1.33. The meander bar design shall be reevaluated at later stages of the design to make sure the latest guidance is implemented.

4.3.2.1 Design Concept

The channel is designed as a pool-riffle channel. Channel complexity features for the SR 308 crossing are designed to provide habitat and allow for natural stream processes. The channel complexity features for this crossing include LWM in restored open channel areas and meander bars within the crossing for habitat. LWM are wood structures (trunks) larger than 6 feet in length and greater than 6 inches in diameter. When LWM is used appropriately within a channel, it can provide bank protection and channel resilience, and can offer benefits for aquatic habitat. Habitat provided by LWM can help aquatic life cover from predators and can contribute to hyporheic flows, cooler waters, and gravel/sediment retention. Preformed pools are not recommended through the crossing. Meander bars will mimic forcing elements typically found in pool-riffle systems to natural create pools and prevent a shift to a plane-bed morphology through the crossing. The design will incorporate meander bars so that a low-flow channel can be introduced with enough complexity to facilitate fish passage through the structure. The bed and bank morphology of the existing channel is stable; vegetation on the bank contributes to the stability of the channel. In open channel areas upstream and downstream of the proposed crossing, LWM will be used to add channel complexity and refuge for fish.

The project will reconstruct 450 feet of channel, roughly 296 feet of which is expected to be within the new structure, if a culvert is constructed, leaving 154 feet of open channel length. A bridge design would increase the open channel length along the constructed reach. For 450 feet of reconstructed channel, the 75th percentile wood targets, in accordance with Fox and Bolton and the WSDOT Hydraulics Manual are 15 key pieces and 52 total pieces of LWM (Fox and Bolton 2007; WSDOT 2022a). To achieve the recommended volume of wood, the LWM would need to be up to 4 feet diameter at breast height (DBH). Pieces this size would be difficult to obtain, difficult to construct, and excessive for this 10.0-foot-wide channel. For these reasons, the recommended wood volumes are reduced at this site. Because the length of reconstructed channel is the same for either structure type, the 75th percentile wood targets are the same for either option.

Key pieces will consist of self-ballasting logs that are generally 1.5 feet to 2.0 feet DBH and 24 feet to 30 feet long. Additional pieces in the 1-foot DBH size range will be included along with smaller more mobile wood in the 0.5-foot DBH range. Mobile pieces would move only during extreme events and may not move far even during high flows, because they are likely to rack against larger wood pieces. The project is anticipated to use anchoring for LWM until stability calculations are completed that indicate otherwise.

Figure 40 shows a conceptual layout of wood recommended for this channel assuming a culvert structure is selected. Note that the length of modified channel outside of the crossing will be limited relative to the overall length of the crossing. As a result, placement of LWM in proximity to the crossing (less than 50 feet) will be required. The 75th percentile wood targets are not feasible for this crossing as the number and size of the LWM would be overly dense and counterproductive to fish passage. As shown in Figure 40, the proposed design contains half of the targeted total number of LWM pieces and number of key pieces. Figure 41 shows a conceptual layout of wood recommended for this channel assuming a bridge structure is selected. Note that the increased length of open channel as compared to the culvert concept allows for the targeted total number of pieces and number of key pieces to be achieved. The LWM within the footprint of the existing roadway embankment shown in Figure 41 primarily remains within the minimum hydraulic opening and consists of smaller sizes of LWM to accommodate potential slope stability or shear walls that may be constructed in conjunction with a bridge structure type.

The orientation of the LWM in Figure 40 and Figure 41 relative to the flow was selected to create fish habitat and prevent scour near the proposed structure by creating hydraulic stream features as shown in Table 10. Table 10 is adapted from Clinton River Watershed Council's *Field Manual on Maintenance of Large Woody Debris for Municipal Operation and Maintenance Crews (CRWC 2007)*. Additional LWM may be stacked above the 100-year flow depth or buried in the stream to achieve a larger number of LWM pieces or a greater volume of LWM on the project. A low-flow channel will be formed through the LWM that will connect with the low-flow channel formed between meander bars under the structure. Meander bars as well as LWM are designed to be immobile during low and medium flow events. This helps to maintain the low-flow channel even after a larger flow event. This low-flow channel will ensure that during low flows, there is no risk of fish stranding in the dry bed. The LWM pieces not only can provide stability but also could provide small pools, which would improve habitat and provide refuge to juveniles when they are migrating upstream.

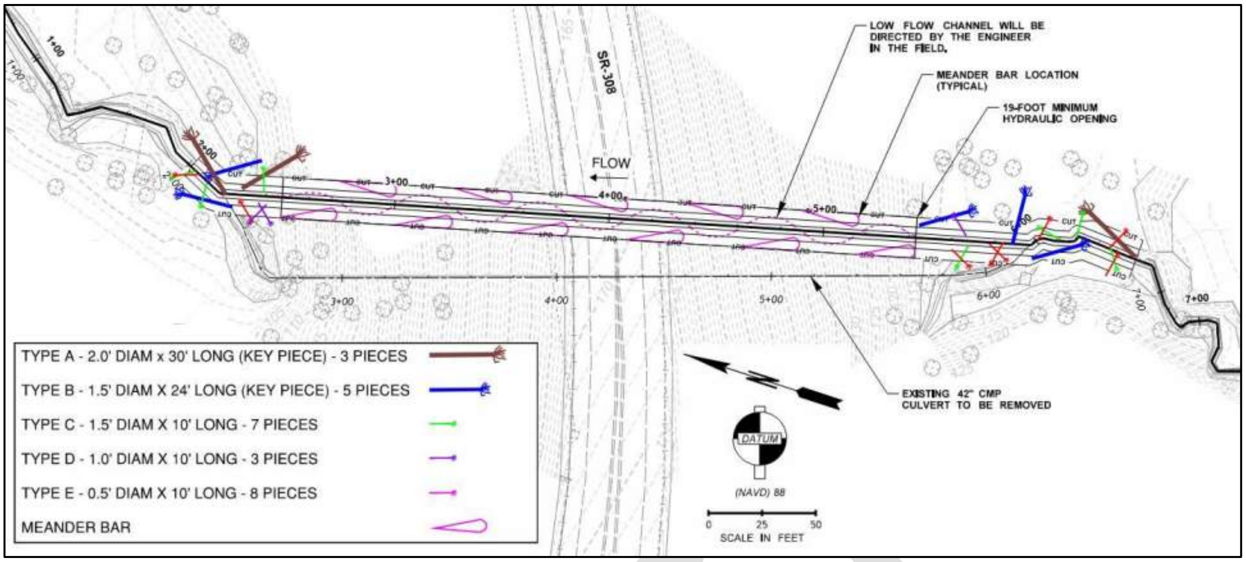

Figure 40: Conceptual layout of habitat complexity for culvert structure

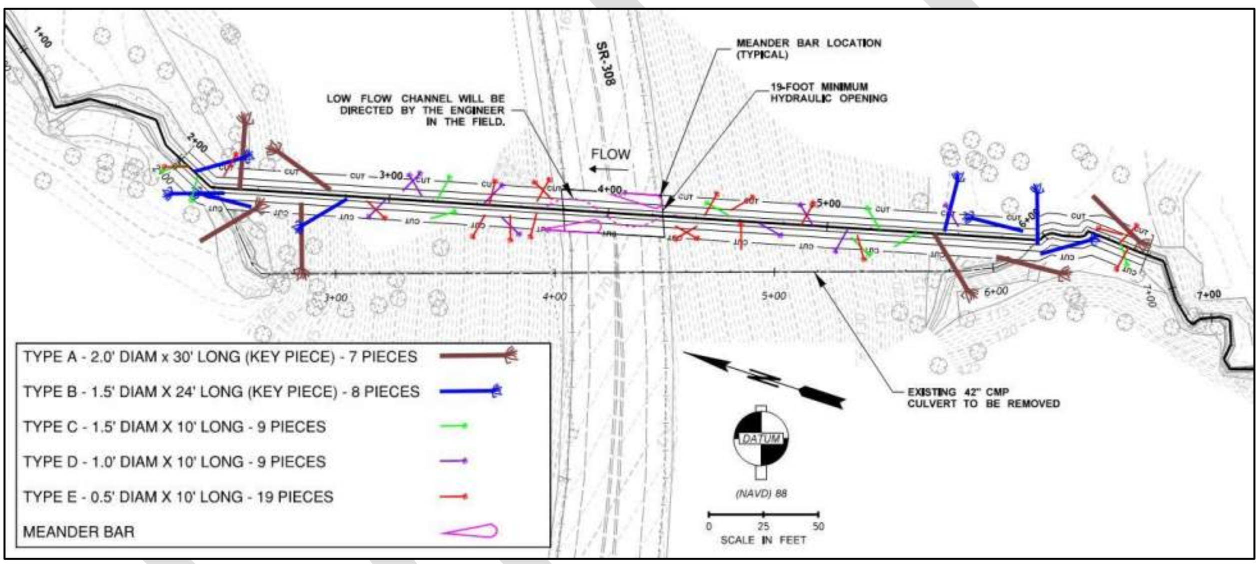

Figure 41: Conceptual layout of habitat complexity for bridge structure

Table 10: Changes in Stream Morphology Created by Flow Alterations

Orientation of LWM relative to Flow	Upstream Morphology Changes	Downstream Morphology Changes
Parallel	Scour Pool	Bar or Island
Angled	Pool and Bar	Pool and Bar
Perpendicular: on streambed	Depositional Zone	Scour Pool
Perpendicular: above streambed	Scour Pool	Scour Pool

A Conceptual Restoration Plan (CRP) will be developed at a later draft version of this PHD.

4.3.2.2 Stability Analysis

Large wood stability analysis will be completed at final design.

5 Hydraulic Analysis

The hydraulic analysis of the existing and proposed SR 308 Little Scandia Creek crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D Version 3.2 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using SMS Version 13.1.14 (Aquaveo 2021).

Two scenarios were analyzed for determining stream characteristics for Little Scandia Creek with the SRH-2D models: (1) existing conditions with the 3.5-foot diameter, 313.6-foot-long corrugated metal culvert and (2) proposed conditions with the proposed 19-foot minimum hydraulic opening installed.

5.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

5.1.1 Topographic and Bathymetric Data

The channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the WSDOT Project Engineer's Office (PEO), which were developed from topographic surveys performed by WSDOT on November 23, 2021. The survey data was supplemented with light detection and ranging (LiDAR) data (WA LiDAR Portal 2017). Proposed channel geometry was developed from the proposed grading surface created by DEA. All survey and LiDAR information is referenced against the NAVD 1988 vertical datum, and NAD 1983 State Plan Washington North horizontal datum. The survey and LiDAR data revealed rather consistent channel shape and confined floodplain banks. About 250 feet upstream of the SR 308 crossing, the surveyed thalweg elevation varies in elevation by multiple feet over the course of 5 feet to 20 feet of stream length. These rapid changes in the thalweg elevation create several small pools that are 2 feet to 3 feet deeper than the rest of the modeled reach in existing and proposed conditions.

Topographic surface development for the site geometry of proposed conditions used InRoads to regrade the surface through the crossing, extending approximately 85 feet upstream and 65 feet downstream of the existing SR 308 crossing. Modeling of the proposed conditions used a single cross section mimicking the channel geometry in the reference reach. Upstream and downstream match points to the existing profile were selected to find an average, consistent grade that would minimize the increase in the channel's longitudinal gradient.

5.1.2 Model Extent and Computational Mesh

The model extends from approximately 514 feet upstream of the existing SR 308 MP 1.33 inlet to approximately 733 feet downstream of the existing outlet, covering a total channel length of 1,561 feet. Discontinuities near the model edges are typically resolved within the nearest few model computation cells. More than 150 cells in the computational mesh along the channel centerline from the inlet boundary condition to the crossing and more than 200 cells from the proposed crossing to the outlet boundary condition allow for reliable model computations near the proposed crossing.

The model meshes have an element density that reflects the complexity of the site conditions. The existing conditions model consists of 15,741 elements (see Figure 42), while the proposed conditions model consists of 15,253 elements (see Figure 43). Meshes for both the existing and the proposed conditions utilize quadrilateral elements in the channel and triangular elements over the remaining surface area. The meshes have an approximate vertex spacing of 3.5 feet along the channel banks and an approximate vertex spacing of 35 feet near the outer mesh limits. Vertex spacing is 2.8 feet at the upstream boundary and 1.6 feet at the downstream boundary. The vertex spacing varies through the channel; there is a higher density at the crossing and along channel bends for an increased level of detail at these locations. The SR 308 crossing in the proposed conditions model has an average vertex spacing of 5.0 feet along the structure walls and 2.4 feet at the inlet and outlet.

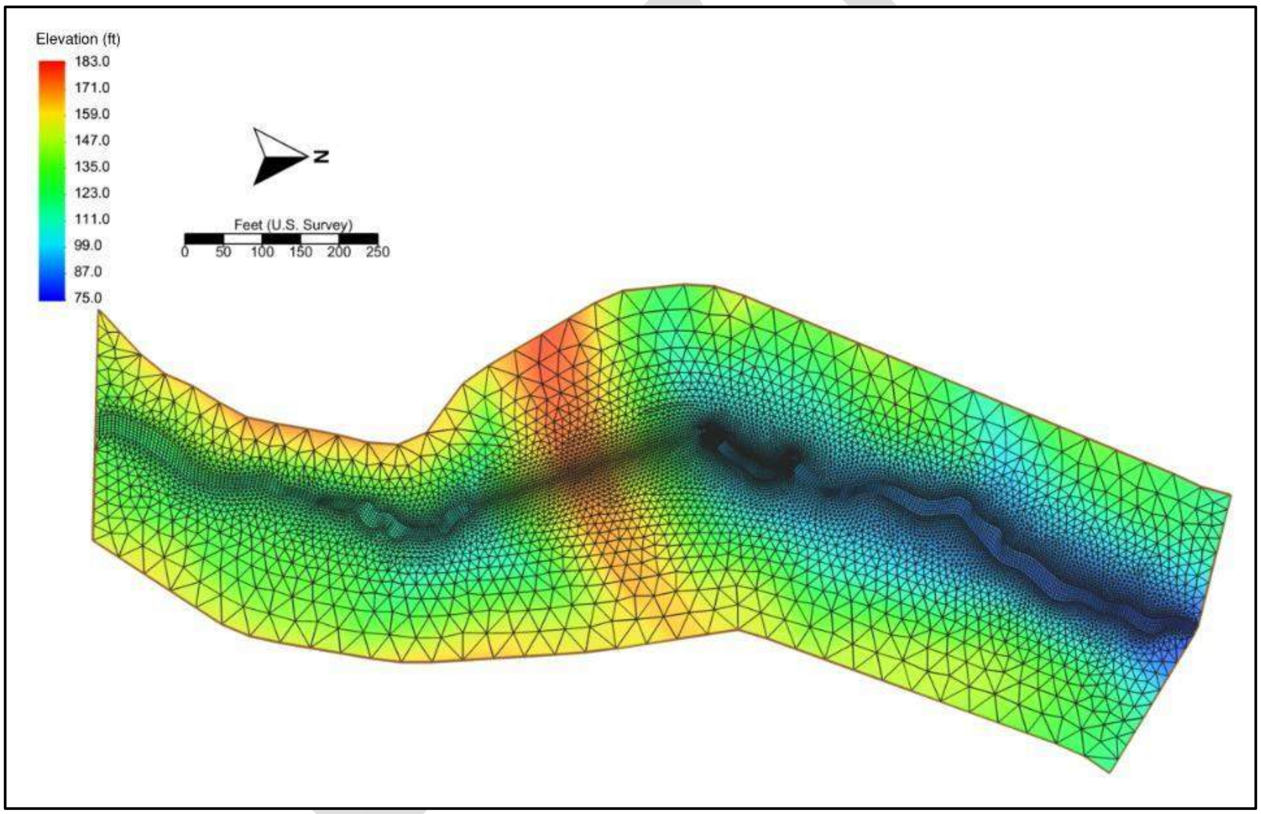

Figure 42: Existing-conditions computational mesh with underlying terrain

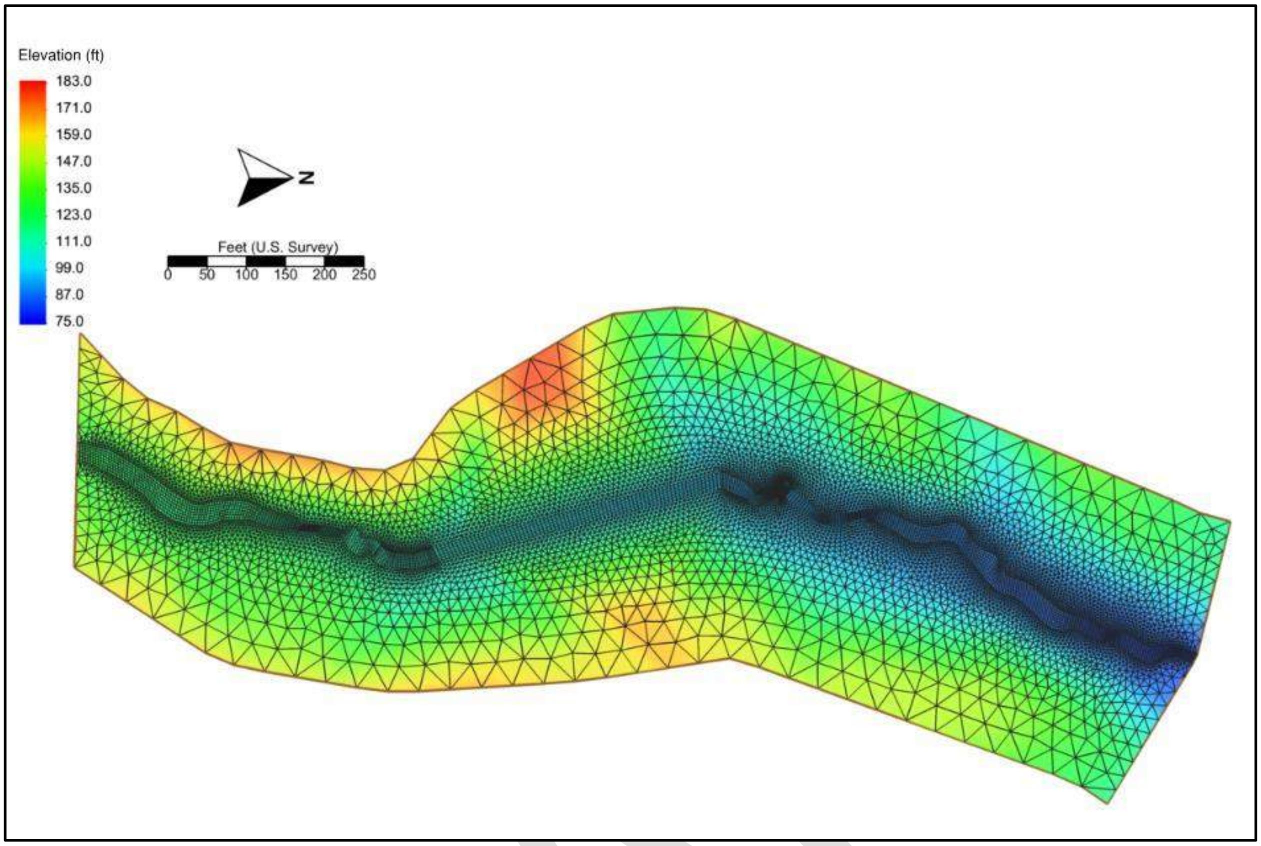

Figure 43: Proposed-conditions computational mesh with underlying terrain

5.1.3 Materials/Roughness

Table 11 lists the roughness coefficients used in the hydraulic modeling, which are taken from *Open Channel Hydraulics* (Chow 1959) and evaluated by visual observation in the field. Existing and proposed conditions used the same roughness values. No-flow areas (i.e., buildings) and unassigned land cover types were not necessary to model the two conditions. Figure 44 and Figure 45 show the spatial distribution of the roughness conditions for the existing conditions and the proposed conditions modeling, respectively.

The existing main channel roughness value represents a gravel and cobble bottom without vegetation in the stream and is representative of upstream downstream conditions. The proposed main channel roughness value represents a slightly coarser gravel and cobble bottom that is proposed for the areas impacted by channel grading including through the structure. The meander bars are comprised of sediment up to 18 inches in diameter, so an above average roughness value was selected from the cobbles with large boulders category of Chow 1959. The channel banks are representative of light brush and vegetation, while the vegetated slopes are similar to the channel banks but have a higher roughness value to account for trees. LWM, to the extent contained in the proposed conditions, is not present in existing conditions. The roughness value for LWM in Table 11 represents dense, large diameter logs, and root wads, as discussed in Section 4.3.2.

Table 11: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Material	Manning's n
Asphalt	0.016
Existing Main Channel	0.04
Proposed Main Channel	0.045
Channel banks	0.06
Meander Bar	0.06
Vegetated slopes	0.065
Large woody material	0.10

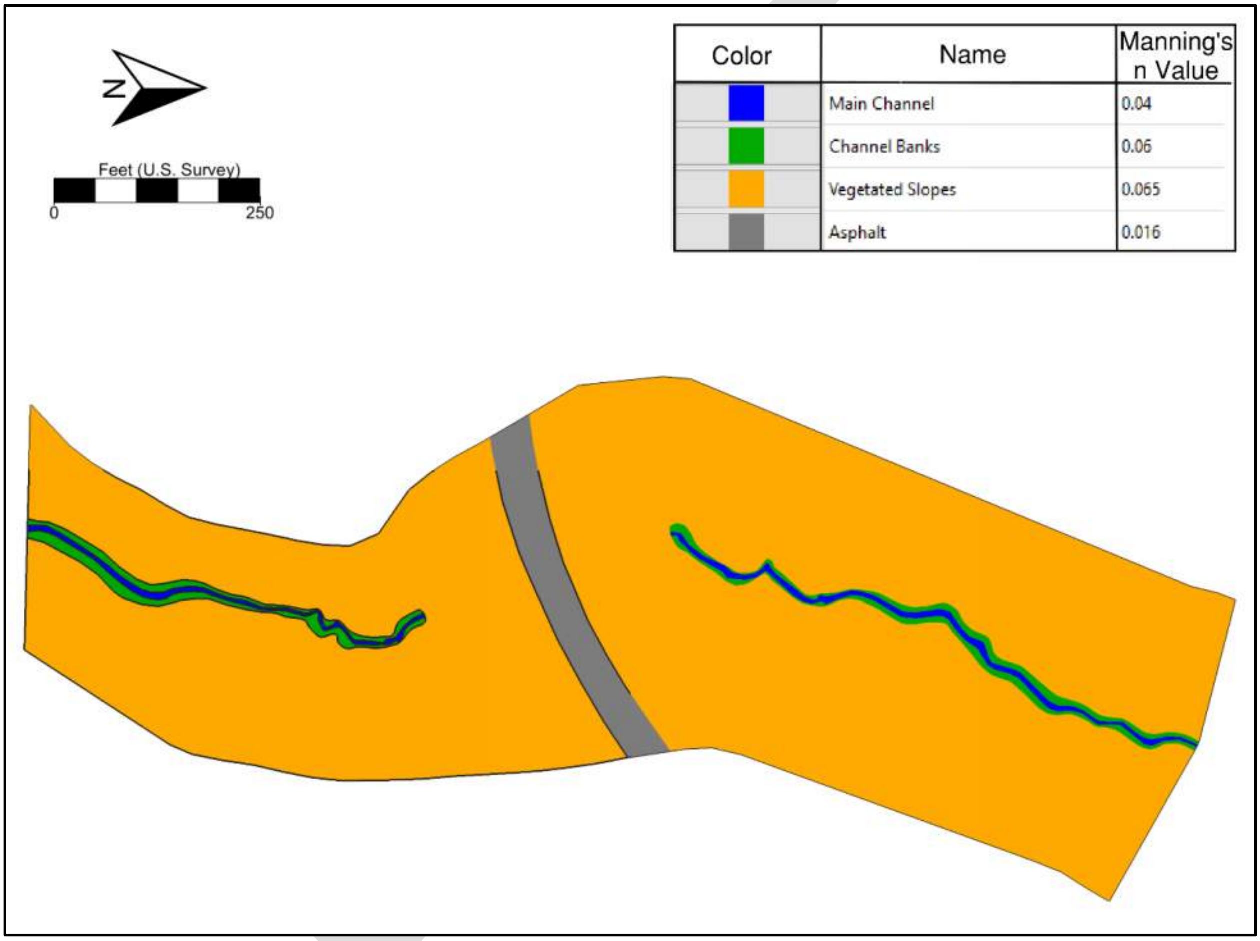

Figure 44: Spatial distribution of existing-conditions roughness values in SRH-2D model

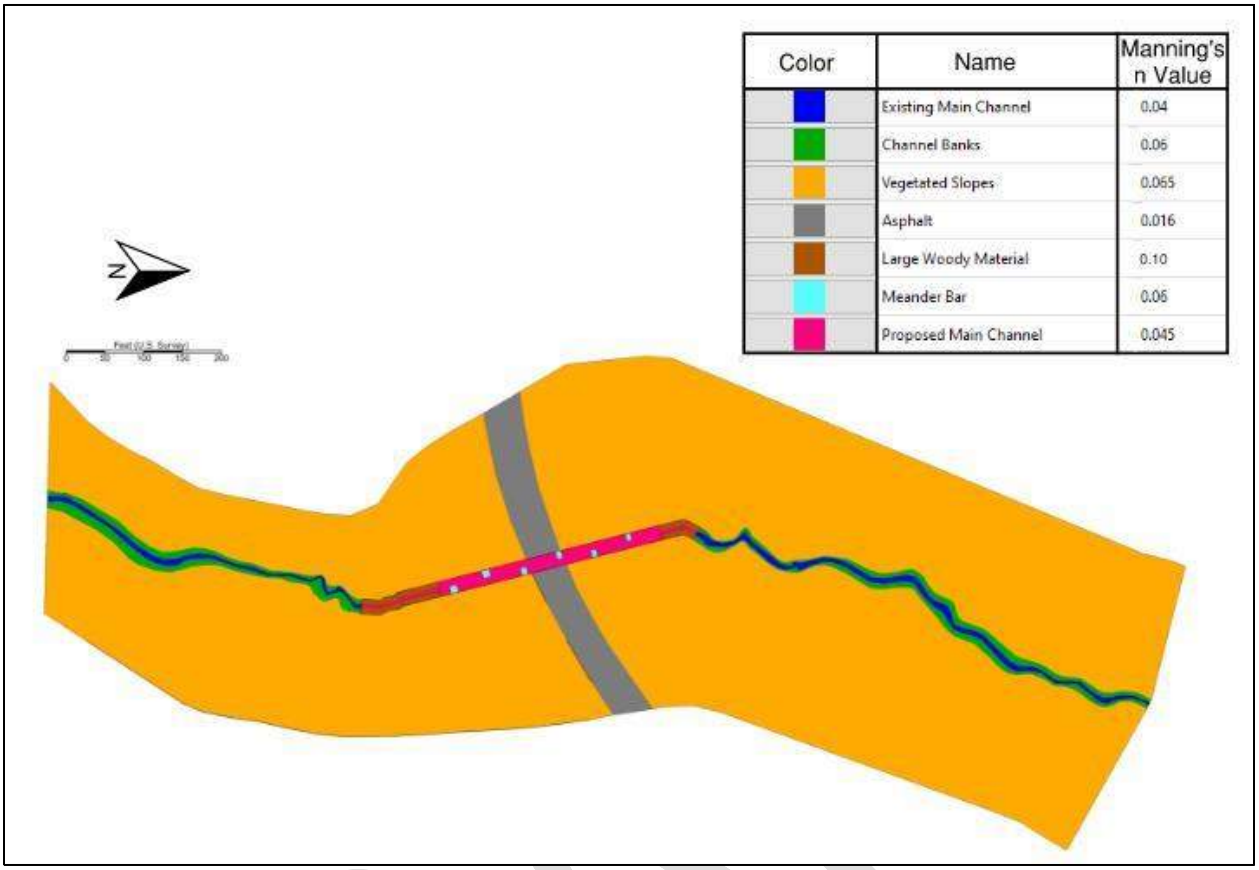

Figure 45: Spatial distribution of proposed-conditions roughness values in SRH-2D model

5.1.4 Boundary Conditions

The existing conditions model contained four boundary conditions: an inflow rate at the upstream limits, paired inlet and outlet boundaries at the existing culvert location, and a WSE at the downstream limits of the models. The existing conditions model used a pair of boundary condition arcs to simulate the existing 3.5-foot-diameter culvert crossing SR 308 at the project site. The SRH-2D model simulates the culvert hydraulics by running the Federal Highway Administration's HY-8 culvert analysis software as an imbedded program within SMS and uses the boundary conditions as the interface between the programs. Culvert geometry, type, and other relevant site data required for the HY-8 computations were compiled from the WSDOT survey and DEA site visit. Figure 46 shows the HY-8 input data for the SR 308 culvert in the existing conditions model.

The proposed conditions model includes two boundary conditions: an inflow rate at the upstream limits and a WSE at the downstream limits of the model. Figure 48 and Figure 49 show the locations of these boundaries in the existing conditions and the proposed conditions models, respectively.

For both the existing and the proposed conditions models, an upstream inflow boundary was specified as a constant flow rate corresponding to the peak flow for the recurrence interval being modeled (i.e., peak flows equal to the 2-, 100-, 500-, and predicted 2080 100-year). Table 6 in Section 3 provides these flow rates. The downstream outflow boundary was set to a constant WSE equal to the normal water depth elevation calculated from a composite Manning's n of 0.045, a slope of 2.11 percent, the flow values corresponding to each event, and a channel cross section based on LiDAR at the boundary condition location. See Figure 46 for the normal depth rating curve based on these parameters. The calculated downstream water surface elevations at the outflow boundary condition were 81.3 feet, 82.0 feet, 82.3 feet, and 82.4 feet for the 2-year, 100-year, 2080 100-year, and 500-year events, respectively. The inflow and outflow boundary conditions were set sufficiently far from the SR 308 MP 1.33 crossing that these boundaries do not influence the hydraulic results at the project site. The model was run in steady-state mode for all simulated flows.

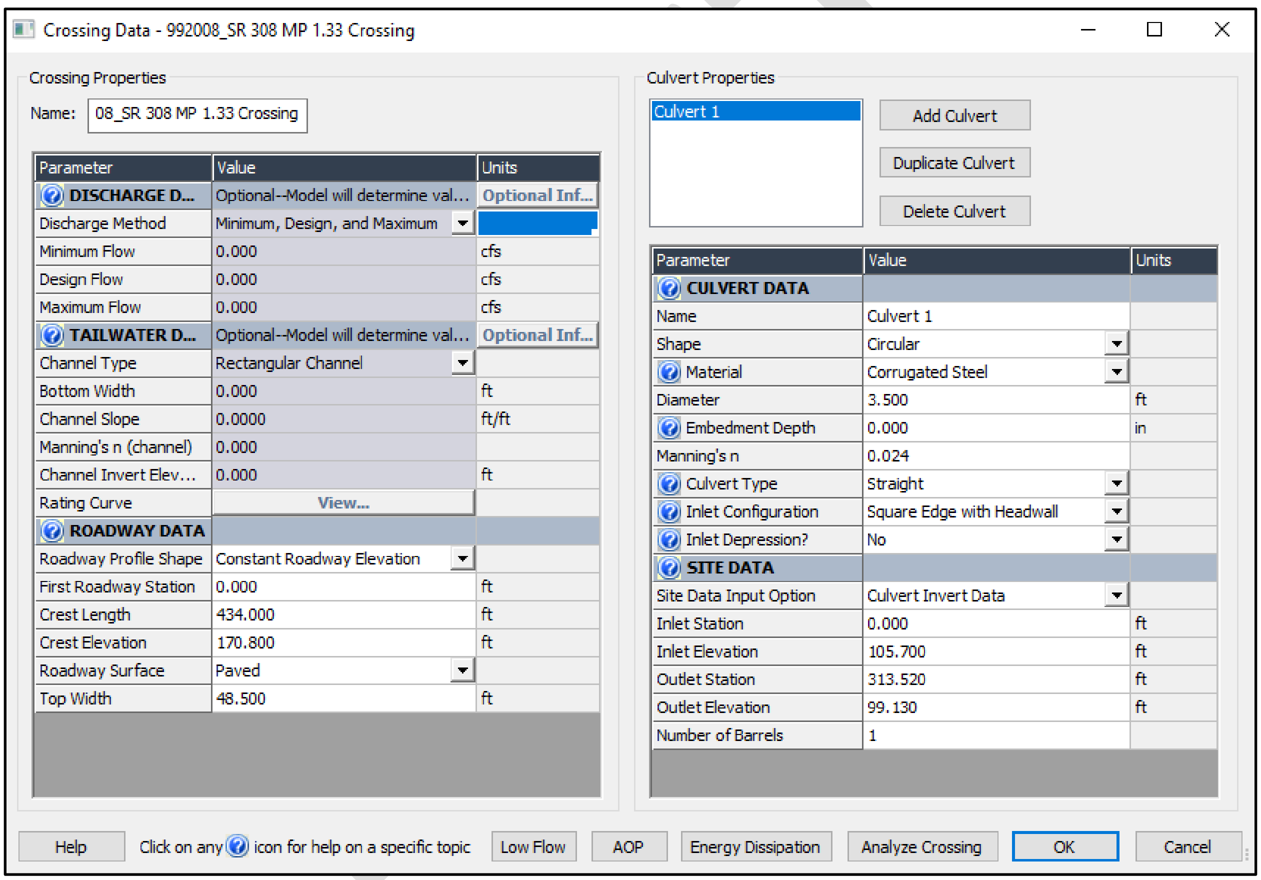

Figure 46: HY-8 culvert parameters

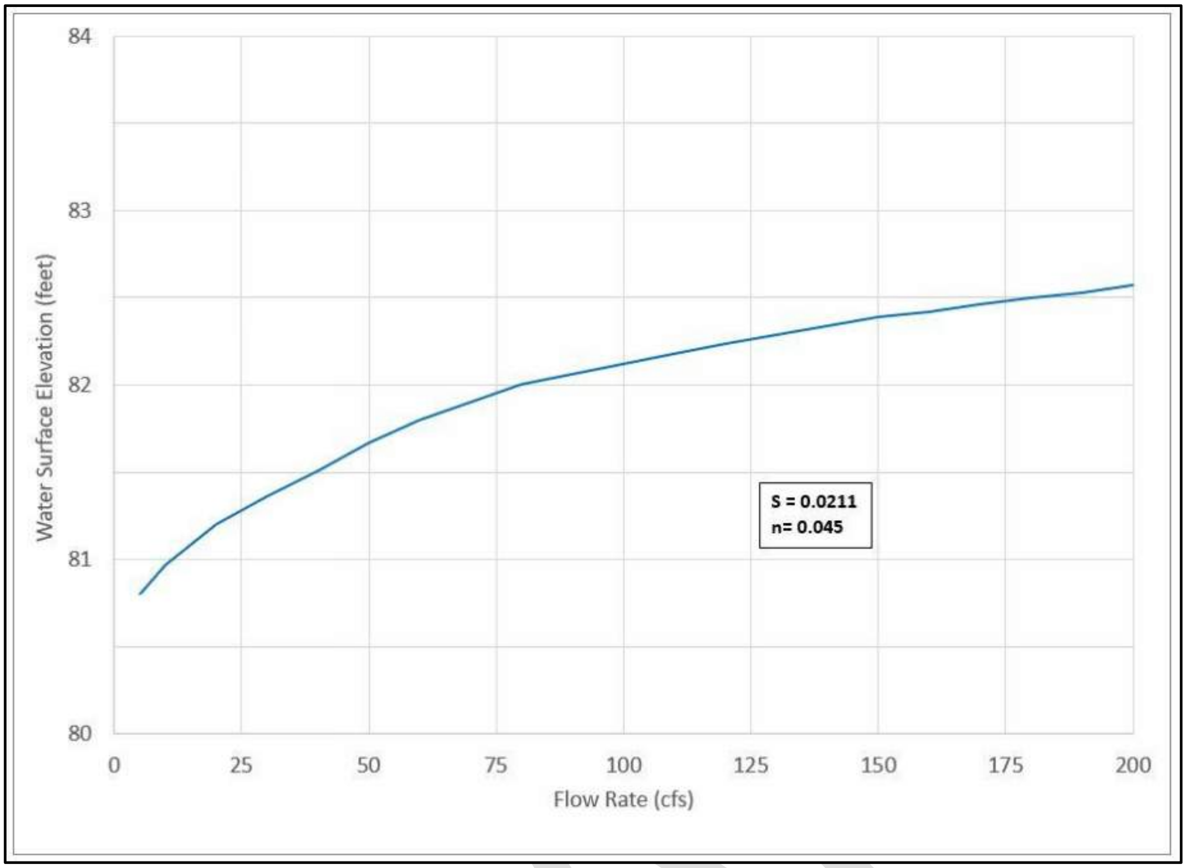

Figure 47: Downstream outflow boundary condition normal depth rating curve

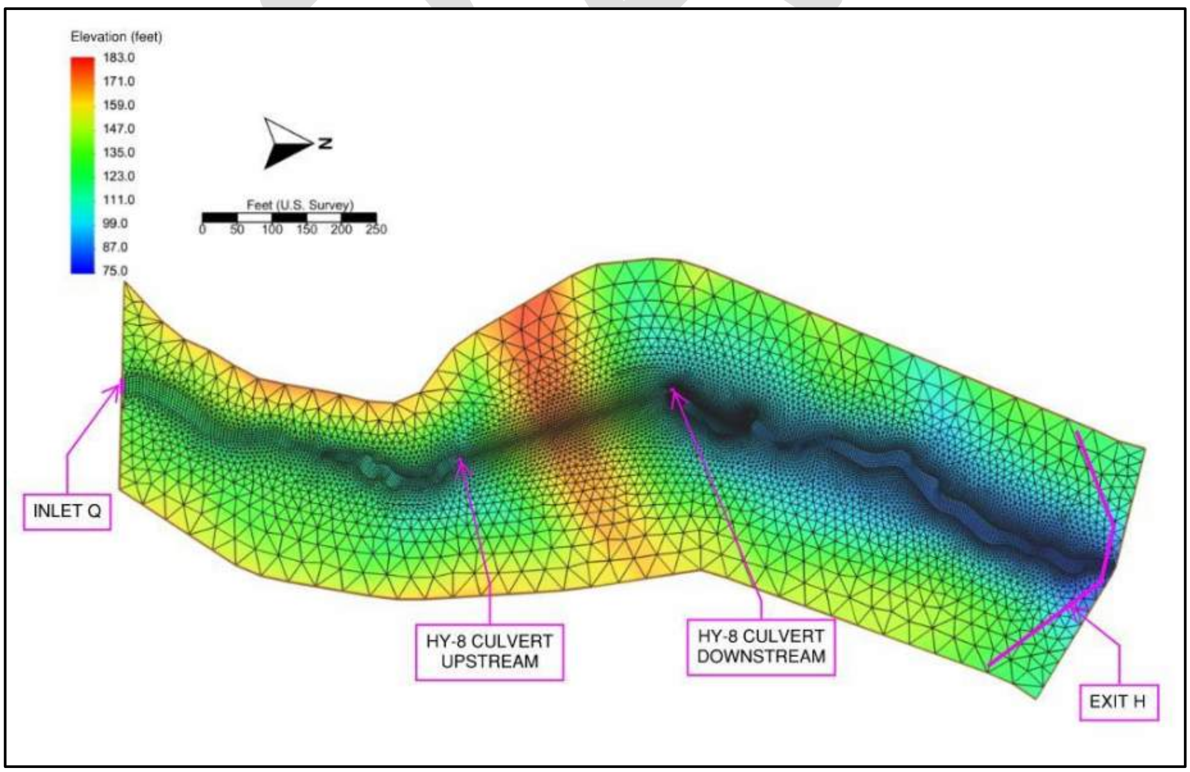

Figure 48: Existing-conditions boundary conditions

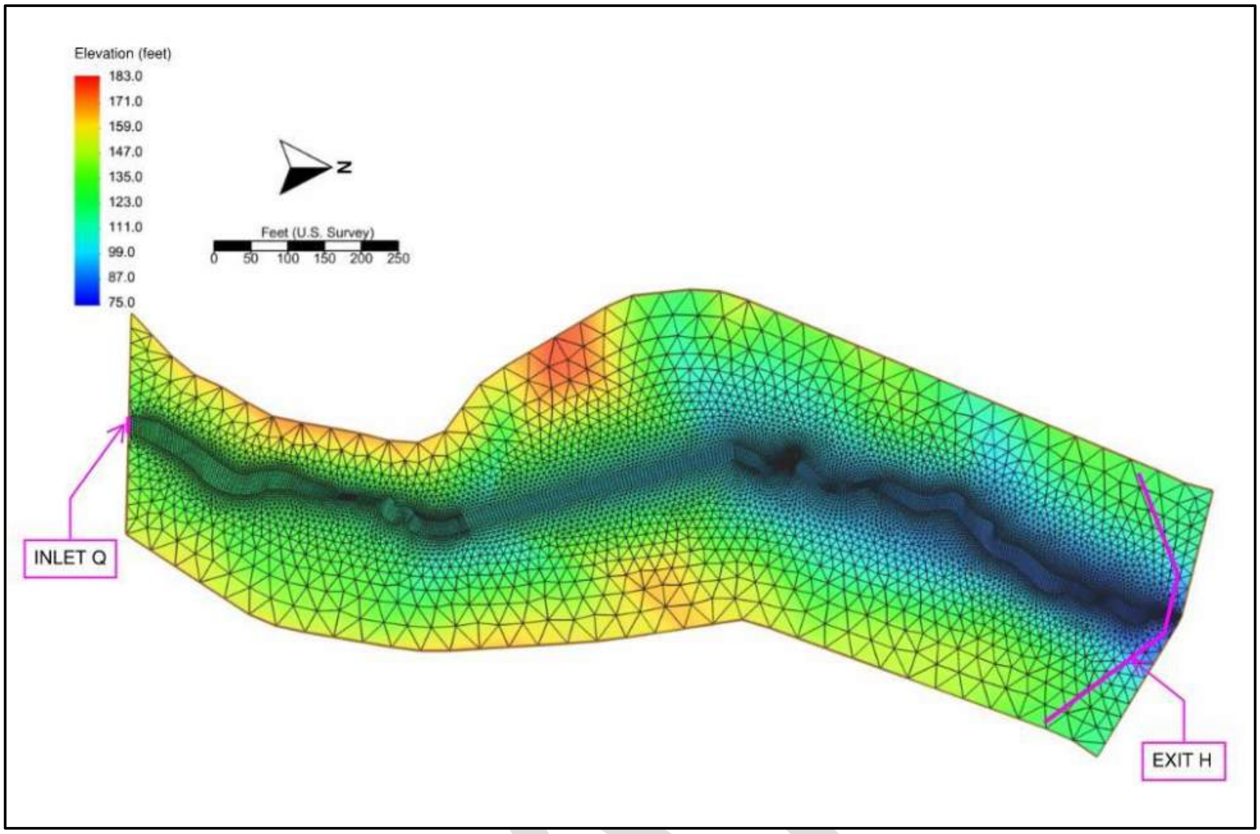

Figure 49: Proposed-conditions boundary conditions

5.1.5 Model Run Controls

The existing and proposed models were run as steady state flow until there was no observable change in WSE upstream or downstream of the crossing. The existing conditions model runs started at time 0 hours and ended at time 6 hours, using 0.5-second time steps. The existing model runs typically achieved steady state conditions in less than 1 hour of simulation time. The proposed conditions model runs started at time 0 hours and ended at time 4 hours, using 1-second time steps. The proposed conditions model runs typically achieved steady state conditions in less than 1 hour of simulation time. Appendix I contains monitor point and monitor line plots showing model stability and continuity over the model run time. Both existing and proposed simulations began with a dry initial condition and event-specific flow values. All simulations used the default parabolic turbulence value of 0.7.

5.1.6 Model Assumptions and Limitations

The model assumes that all the flow in the basin enters the channel at the upstream boundary condition in a uniform condition, even though the runoff between SR 308 and the upstream boundary condition would enter the channel throughout this reach. The meander bars are not reflected in the proposed mesh surface and were simulated only with increases in local channel roughness. The model was run in a steady-state condition. Photographs of the rust line at the existing culvert outlet and field measured bankfull widths provided calibration data as described in Section 3. No high-water debris levels or other indicators were available for calibration.

5.2 Existing Conditions

Figure 50 shows the locations of the cross sections in the model where existing conditions results were measured. Table 12 contains the model results upstream and downstream of SR 308. The existing culvert at the SR 308 crossing conveys all flows between the 2-year and 500-year intervals without overtopping SR 308. Flow splits or multiple openings were not present in the existing conditions model. The maximum modeled flow through the existing structure is 144.3 cfs. WSE profile plots showed a lack of backwater during the 2-year event, but the 100-year and 500-year events cause significant backwater at the SR 308 MP 1.33 crossing (see Figure 51). Main channel extents, and right overbank and left overbank locations were approximated by identifying the 2-year event water surface top widths within the model. See Figure 52 for a typical existing stream cross section with WSEs corresponding to the 2-, 100-, and 500-year events.

Maximum flow depths within the modeled area ranged from 0.5 foot to 4.6 feet during the 2-year event, with a majority of the modeled reach having maximum flows depths of 0.5 foot to 1.5 feet. Velocities during the 2-year event along the stream centerline ranged from 0.5 foot to 9.9 feet per second (fps) in the modeled reach, with a majority of the modeled reach having velocities of 2 fps to 5 fps. The lowest velocities are associated with areas that are backwatered immediately upstream of the culvert during the 100-year and 500-year events. Maximum flow depths within the model varied greatly during the 100-year event due to the backwater condition at the culvert inlet. A maximum depth of 6.9 feet was modeled at the culvert inlet during the 100-year event, compared to the typical maximum depth of 1.5 feet to 2.5 feet downstream of the culvert.

The maximum velocity at the culvert outlet during the 100-year event was 16.7 fps, most likely due to pressurized flow through the culvert. A maximum water depth of 21.3 feet was modeled during the 500-year event at the culvert inlet, which produced velocities at the culvert outlet around 19 fps. Table 13 shows the average main channel and floodplain velocities during the 100-year event taken at the cross sections shown in (Figure 50). Main channel velocities ranged from 1.6 fps to 6.6 fps at the selected cross sections, whereas left overbank and right overbank velocities in the floodplain ranged from 0 fps to 4.1 fps.

Shear stresses were consistently highest in upstream reaches of the model and at the culvert outlet due to the greater velocities at these locations. Reported shear stress immediately upstream of the culvert in the backwatered area during the 100-year and 500-year events was low due to the small velocities at those locations when the model reaches steady state. In the reference reach, typical shear stresses during the 2-year event were less than 1 pound per square foot, while the 100-year event experience shear stresses around 1 pound per square foot, and the 500-year event produced shear stresses around 1.5 pounds per square foot.

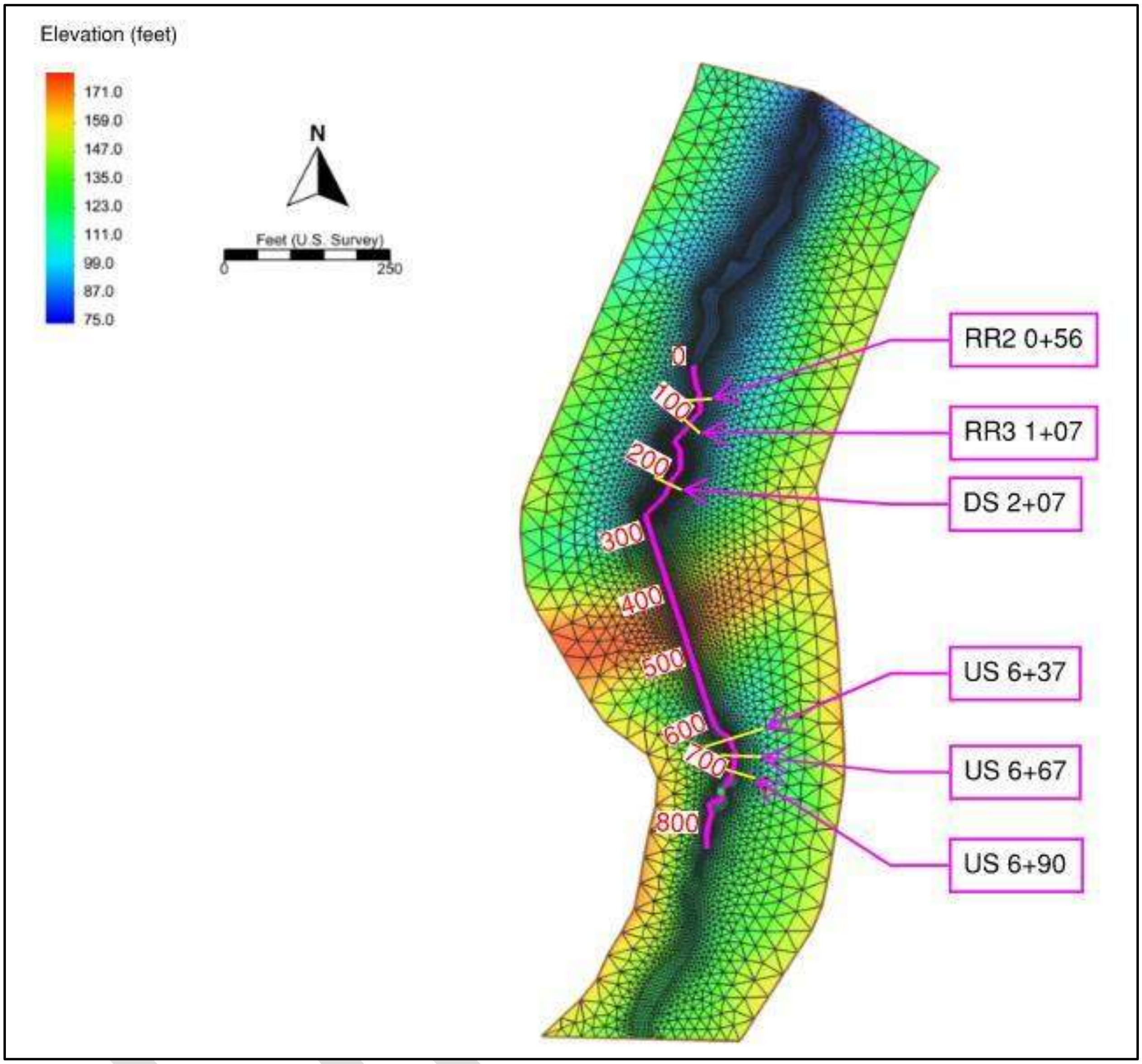

Figure 50: Locations of cross sections used for existing conditions results reporting

Table 12: Average main channel hydraulic results for existing conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year
Average WSE (ft)	RR2 0+56	91.0	91.8	92.3
	RR3 1+07	92.3	93.3	93.9
	DS 2+07	94.5	95.2	95.6
	Structure	NA	NA	NA
	US 6+37	108.0	110.9	125.2
	US 6+67	109.2	110.9	125.2
	US 6+90	109.7	111.0	125.2
Max depth (ft)	RR2 0+56	0.8	1.7	2.2
	RR3 1+07	1.3	2.3	2.9
	DS 2+07	0.9	1.5	2.0
	Structure	NA	NA	NA
	US 6+37	1.4	4.3	18.6
	US 6+67	1.3	3.0	17.3
	US 6+90	1.3	2.6	16.9
Average velocity (ft/s)	RR2 0+56	3.9	6.4	7.1
	RR3 1+07	2.5	4.6	5.6
	DS 2+07	3.7	6.6	7.9
	Structure	NA	NA	NA
	US 6+37	2.2	1.7	0.2
	US 6+67	2.7	2.6	0.2
	US 6+90	3.1	3.9	0.2
Average shear (lb/SF)	RR2 0+56	1.8	3.0	3.2
	RR3 1+07	0.5	1.2	1.6
	DS 2+07	1.1	2.4	3.3
	Structure	NA	NA	NA
	US 6+37	0.7	0.1	0.0
	US 6+67	0.7	0.3	0.0
	US 6+90	1.7	1.2	0.0

Main channel extents were approximated using modeled 2-year event water surface top widths.

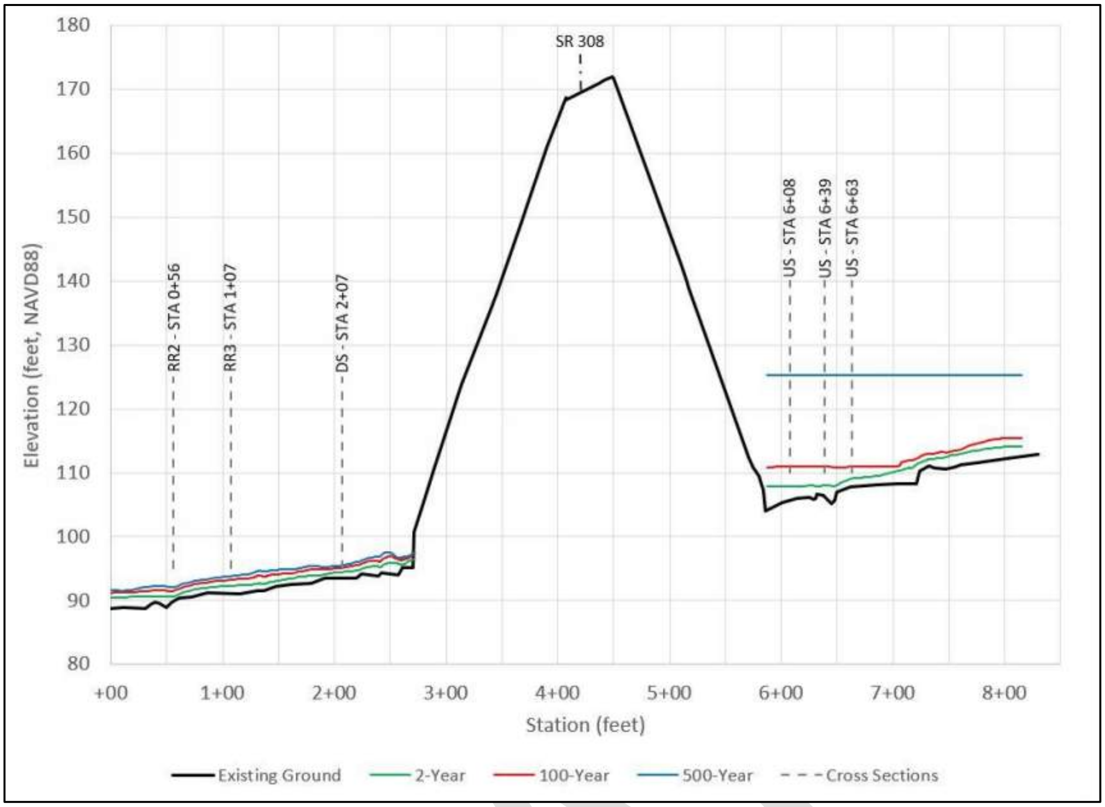

Figure 51: Existing-conditions water surface profiles

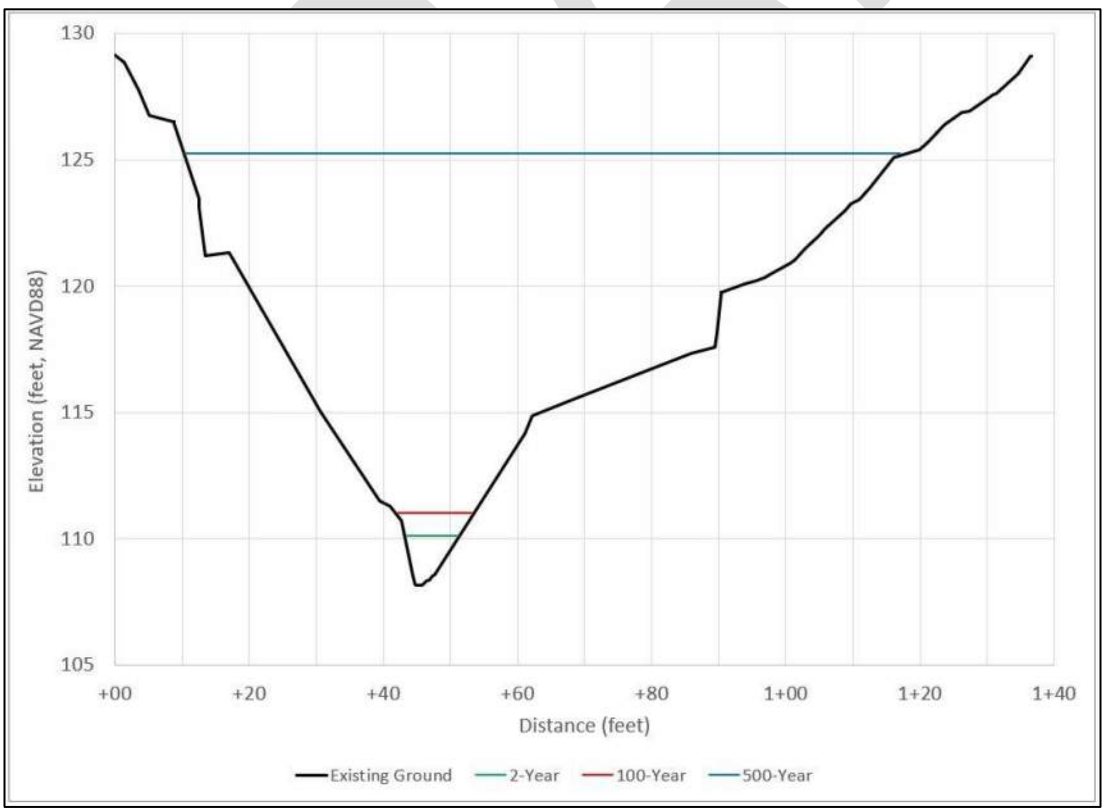

Figure 52: Typical upstream existing channel cross section looking downstream (STA 6+97)

Table 13: Existing-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities tributary scenario (ft/s)		
	LOB[a]	Main channel	ROB[a]
RR2 0+56	3.0	6.4	2.3
RR3 1+07	2.1	4.6	1.2
DS 2+07	0.0	6.6	3.9
Structure	NA	NA	NA
US 6+37	0.6	1.7	0.4
US 6+67	0.8	2.6	0.6
US 6+90	2.7	3.9	1.5

[a] Right overbank (ROB) and left overbank (LOB) locations were approximated using modeled 2-year event water surface top widths.

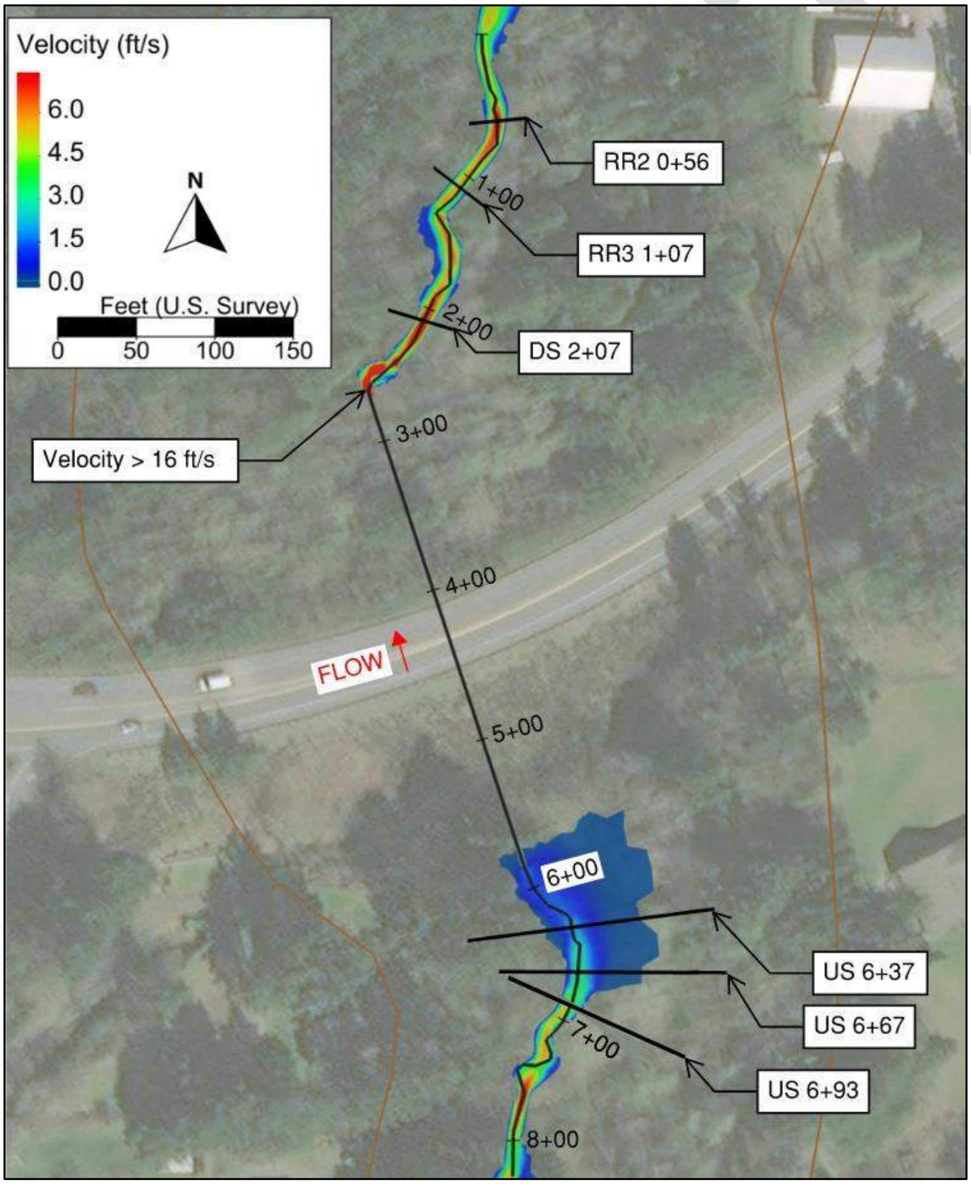

Figure 53: Existing-conditions 100-year velocity map with cross section locations

5.3 Natural Conditions

A natural-conditions model was not required, because the system is confined.

5.4 Proposed Conditions: 19-foot Minimum Hydraulic Width

The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic modeling assumes vertical walls at the edge of the minimum hydraulic width unless otherwise specified. See Section 4.2.2 for a description of how the minimum hydraulic width was determined. The hydraulic model contains 2:1 (H:V) cut slopes at the edge of the minimum hydraulic opening instead of vertical walls. The difference in the hydraulic results is minimal between using cut slopes and vertical walls at the edge of the minimum hydraulic opening on this site because the largest flows barely interact with the minimum hydraulic opening. Additional modeling not contained in this report showed that the additional channel volume provided by the cut slopes produces 2080 100-year and 500-year WSE up to 0.03 feet lower than utilizing vertical walls as well as velocities up to 0.1 fps slower. For these reasons the differences were considered negligible, and the vertical walls were not added to the proposed model for reporting.

The proposed conditions model uses the same configuration as the existing model except that the SR 308 culvert was replaced with the 19-foot hydraulic opening width entered as an open channel cut across SR 308. This approach does not use HY-8 at this crossing. The proposed conditions model shifts the alignment of the crossing to the east, as described in Section 4.1.2. The shift in the alignment reduces the length of stream by 28 feet causing the proposed alignment and stationing to be slightly different than the existing alignment and stationing. Although the upstream cross sections have different stationing between existing and proposed conditions, they are located in the same locations on the stream between the two conditions. Table 14 presents the calculated WSE, velocity, depth, and shear stress from the proposed conditions SRH-2D model for the 2-, 100-, 500-, and predicted 2080 100-year peak flows at the stream locations shown in Figure 54. For additional modeled results not included here, see the SRH-2D model results in Appendix H.

The proposed hydraulic opening will eliminate the existing backwater condition at SR 308 and restore water surface elevations and depths to a more natural condition, as shown in Figure 55. The 100-year flow depth through the structure is generally 1.7 feet, which is similar to the typical upstream and downstream depths of 1.8 to 1.9 feet. Figure 56 shows a typical cross section through the proposed crossing, with WSEs corresponding to the design flows. It is anticipated that over time the channel will naturally adjust from the channel forming flows interacting with the meander bars and low flow channel to equilibrate within the structure. As mentioned in Section 4.1.3, long-term degradation through the crossing may reduce the slope of the proposed profile from a 3.2 percent to 1.8 percent , so the depth and velocity through the crossing may more closely match the downstream conditions as the stream profile adjusts.

The modeled maximum flow depths along the length of the modeled area range from 0.5 foot to 2.0 feet during the 2-year event, with a majority of the model having maximum flows depths of 0.8 foot to 1.3 feet. Velocities during the 2-year event along the stream centerline range from 2.0 fps to 6.3 fps in the modeled reach, and a majority of the modeled reach have velocities of

3.5 fps to 5.2 fps. Maximum flow depths during the 100-year event within the model are more consistent because the backwater effect from the existing culvert would no longer be present. A maximum depth of 5.5 feet is upstream of the crossing during the 100-year event at a location of an existing pool feature, while the model typically has maximum depths between 1.5 feet and 2.1 feet.

Velocities during the 100-year event (shown in Figure 57) along the stream centerline range from 1.5 fps to 7.9 fps in the modeled reach, with a majority of the modeled reach having velocities of 4.9 fps to 7.0 fps outside of the crossing and 6.7 fps within the crossing. Table 15 shows the main channel and floodplain velocity results for the 100-year event and the projected 2080 100-year event. Main channel velocities at the selected cross sections increase an average of 15 percent from the 100-year to the projected 2080 100-year event, and the left overbank and right overbank velocities increase an average of 41 percent and 105 percent, respectively. There is a wide range of differences between the floodplain velocities through the structure and adjacent floodplain velocities contained in Table 15. This is due to most of the cross sections analyzed in Table 15 being outside the extents of grading, and therefore have a very different floodplain shape than within the structure. Table 15 contains a zero value for the right overbank area at station 0+56 and left overbank area at station 6+63 due to the steepness of the banks. For the most part floodplain interaction is very limited outside the proposed grading due to the incision. The floodplain benches must be added to the proposed channel to accommodate the minimum hydraulic opening.

Shear stresses are consistently lower through the proposed reach than immediately upstream and downstream of the proposed crossing during the 2-year, 100-year, 2080 100-year, and 500-year events. The average main channel shear stresses through the crossing match the average or are slightly below the average shear stresses measured at the seven cross section locations reported in Table 14 for all four flows analyzed.

The maximum depth through the structure is generally consistent with the maximum depths at the two cross sections analyzed within the reference reach shown in Table 14, while the velocities through the structure are higher than the reference reach across all flow scenarios. This is due to the difference in channel slopes and the proximity of the cross sections to pools (Figure 55). The structure has a channel slope of 3.2 percent while the reference reach and downstream portions of the stream have a slope of 2.4 percent. The difference in channel gradient was preferred by co-managers over impacting additional habitat. Another reason for slightly shallower depths and faster velocities is the difference in cross section shape above bankfull width. As described in Section 4.1.1 and shown in Figure 38, the proposed channel matches the channel shape of the reference reach below the BFW. However, the proposed channel contains floodplain benches to achieve the minimum hydraulic opening which are not present to the same extent within the reference reach. The structure is not constricting the flow as the 100-year flow barely engages the full minimum hydraulic opening as seen in Figure 56. Station 6+08 is within the high roughness area dominated by LWM which is not present within the structure, so the velocity at that station and does not represent what flows may do within the structure. Stations 6+39 and 6+63 provide better comparisons to the structure where the channel slopes and roughness values are similar to the structure. The velocities through the structure across all flow scenarios are 16 percent greater than the velocities at stations 6+39 and 6+63.

Table 14: Average main channel hydraulic results for proposed conditions

Hydraulic parameter	Cross section	2-year	100-year	Projected 2080 100-year	500-year
Average WSE (ft)	RR2 0+56	91.1	91.7	92.3	92.4
	RR3 1+07	92.3	93.3	93.8	94.0
	DS 2+07	94.9	95.6	96.0	96.1
	TS 4+00	101.0	101.6	101.9	102.0
	US1 6+08	107.8	108.6	109.0	109.1
	US2 6+39	108.8	109.6	109.9	110.0
	US3 6+63	109.7	110.4	110.7	110.8
Max depth (ft)	RR2 0+56	0.8	1.6	2.2	2.3
	RR3 1+07	1.3	2.3	2.8	3.0
	DS 2+07	1.1	1.8	2.2	2.4
	TS 4+00	1.0	1.7	1.9	2.0
	US1 6+08	1.1	1.9	2.2	2.3
	US2 6+39	1.1	1.9	2.3	2.3
	US3 6+63	1.2	2.1	2.5	2.6
Average velocity (ft/s)	RR2 0+56	4.1	6.4	7.3	7.4
	RR3 1+07	2.5	4.6	5.5	5.7
	DS 2+07	3.0	4.9	5.6	5.8
	TS 4+00	3.3	6.1	7.0	7.3
	US1 6+08	2.6	4.4	5.0	5.1
	US2 6+39	2.8	4.8	5.6	5.9
	US3 6+63	3.2	5.2	6.4	6.8
Average shear (lb/SF)	RR2 0+56	1.7	2.9	3.0	3.1
	RR3 1+07	0.5	1.2	1.5	1.6
	DS 2+07	1.4	2.8	3.5	3.7
	TS 4+00	1.1	2.1	2.5	2.7
	US1 6+08	1.2	2.8	3.4	3.6
	US2 6+39	1.2	2.6	3.4	3.8
	US3 6+63	1.6	2.8	3.5	3.9

Main channel extents were approximated by using modeled 2-year event water surface top widths.
TS stands for “Through Structure” and represents modeled results within the proposed crossing.

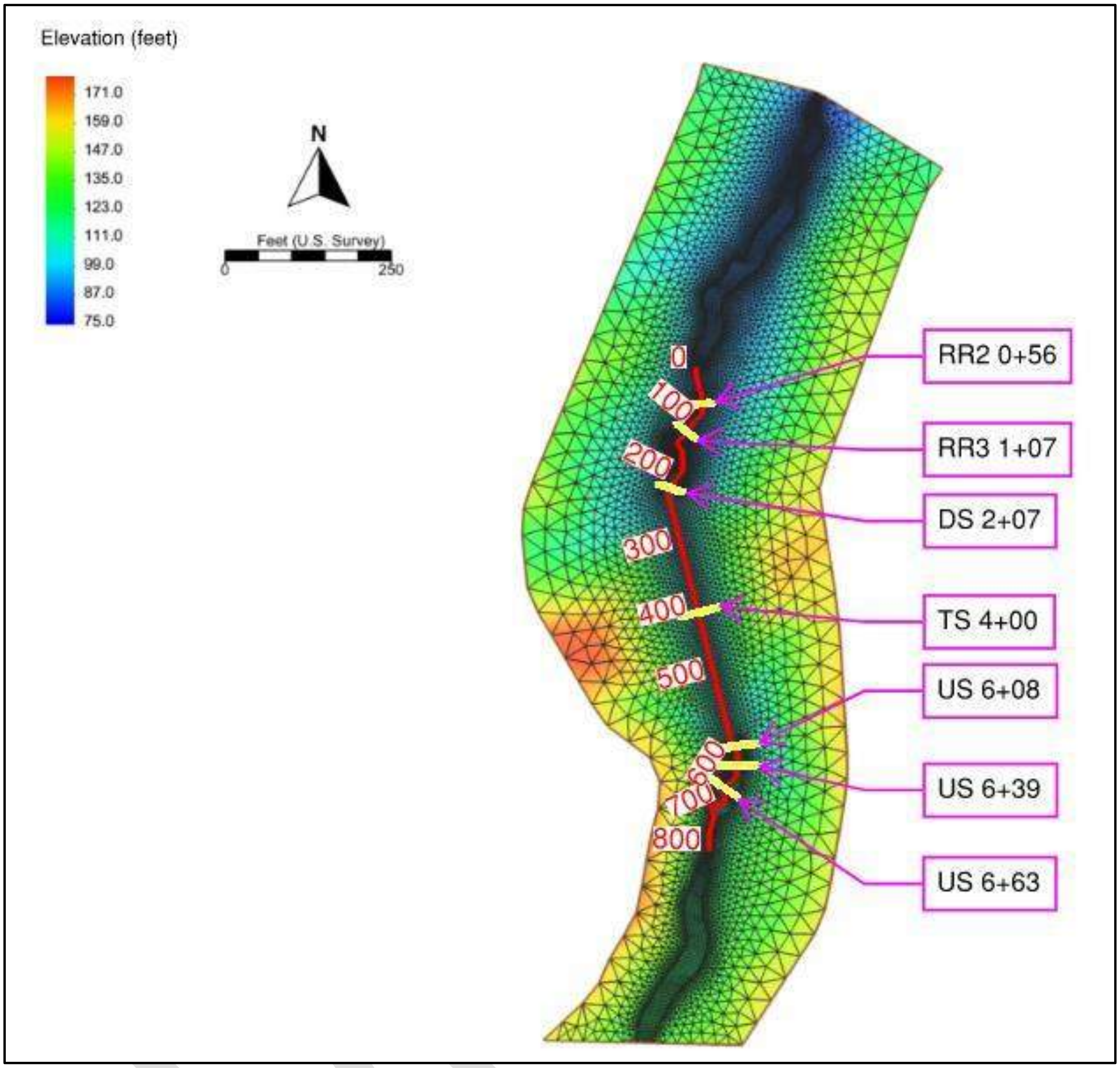

Figure 54: Locations of cross sections on proposed alignment used for results reporting

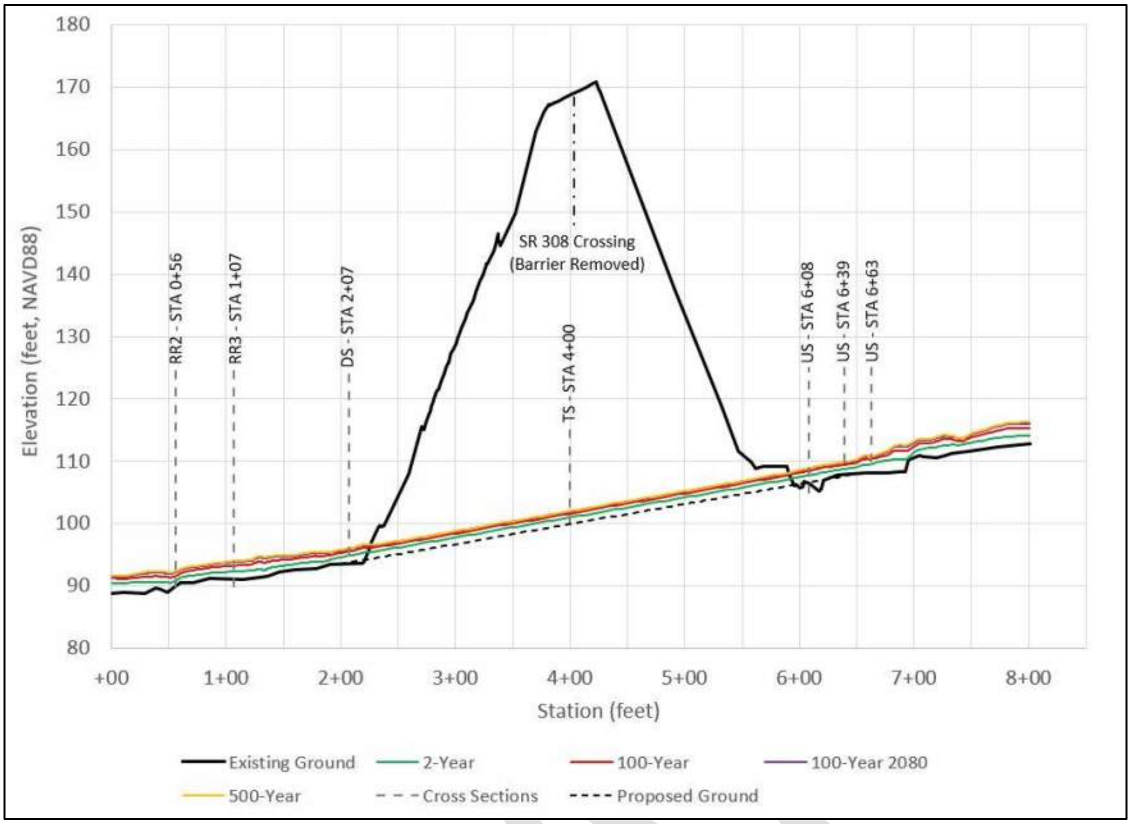

Figure 55: Proposed-conditions water surface profiles

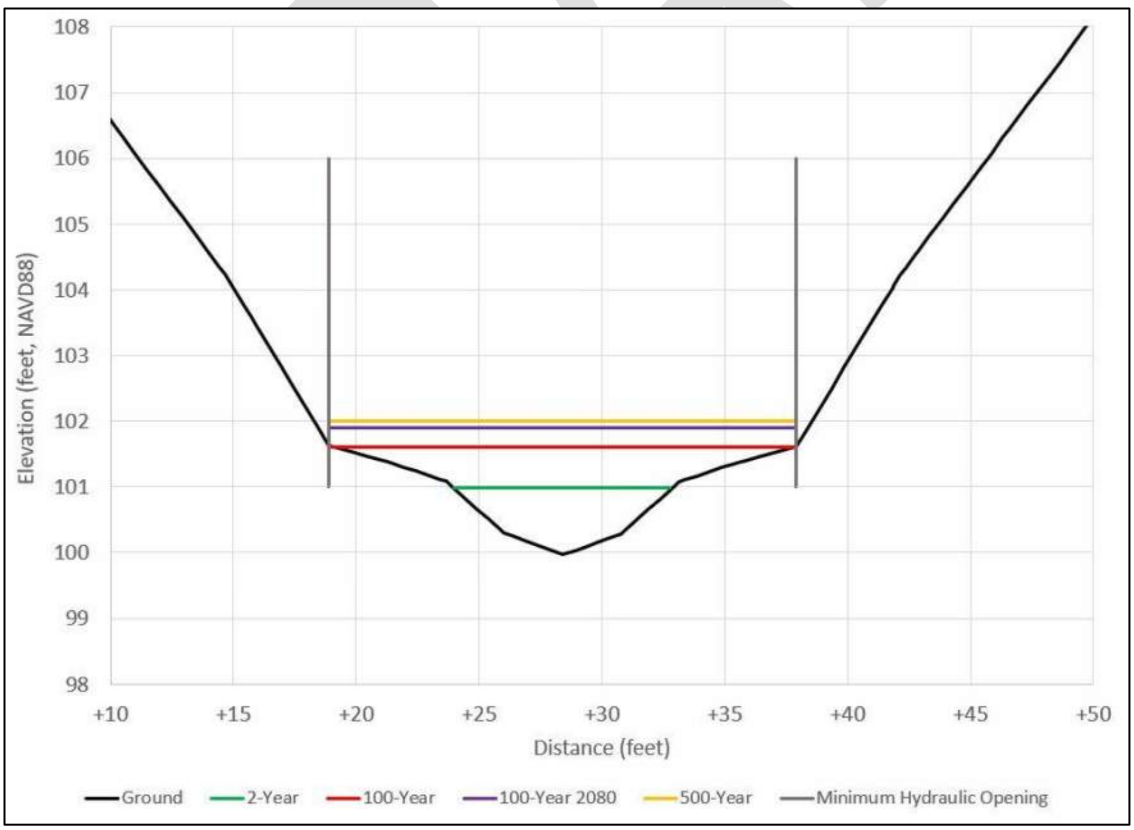

Figure 56: Typical section through proposed structure looking downstream (STA 4+00)

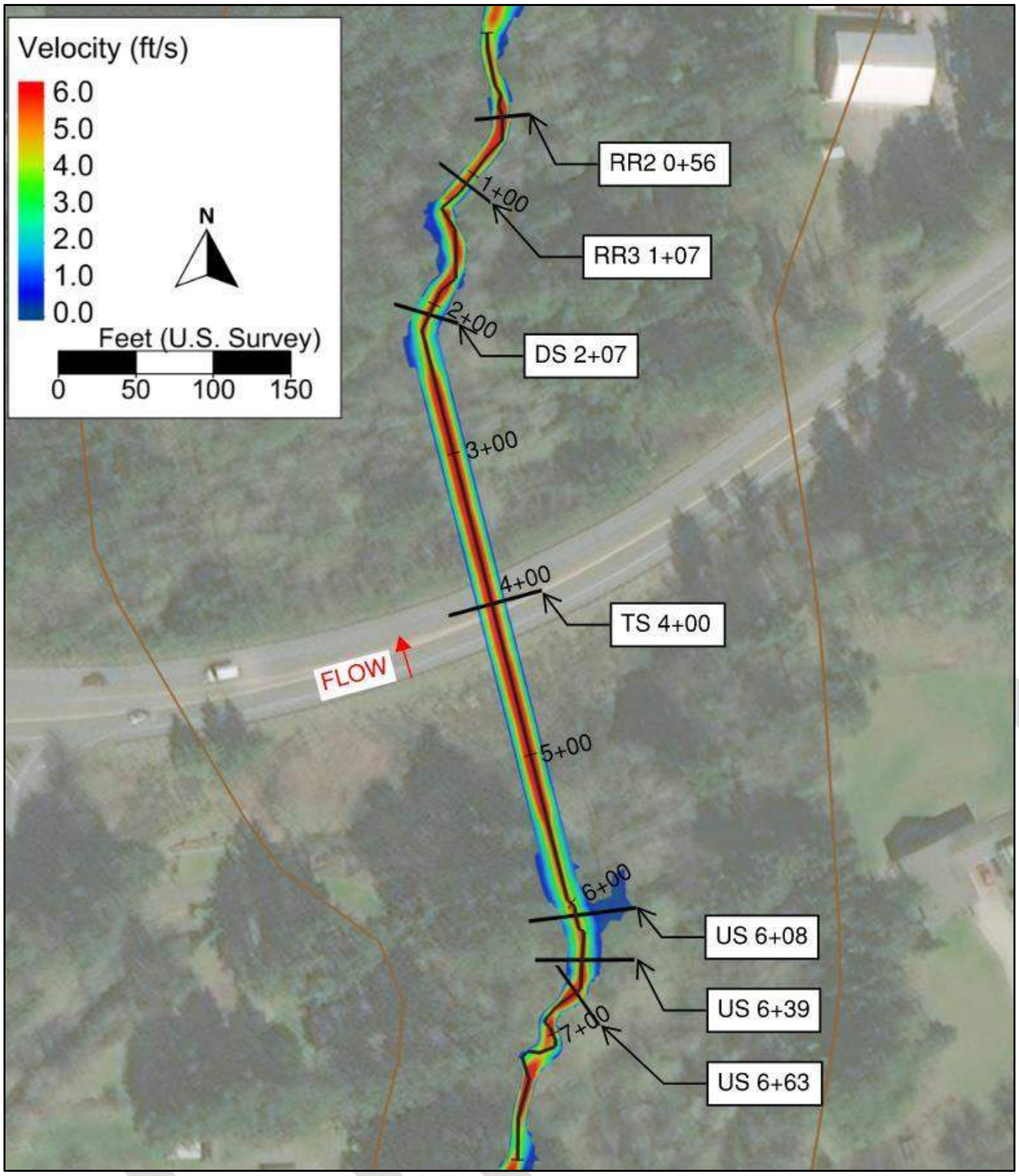

Figure 57: Proposed-conditions 100-year velocity map

Table 15: Proposed-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
RR2 0+56	3.2	6.4	0.0	4.5	7.3	0.0
RR3 1+07	2.1	4.6	1.2	3.4	5.5	2.2
DS 2+07	2.7	4.9	1.4	3.7	5.6	2.3
TS 4+00	2.6	6.1	2.6	4.3	7.0	4.3
US1 6+08	2.4	4.4	0.5	3.1	5.0	1.6
US2 6+39	1.8	4.8	1.6	2.3	5.6	2.9
US3 6+63	0.0	5.2	2.4	0.0	6.4	3.3

[a] Right overbank (ROB) and left overbank (LOB) locations were approximated by identifying the 2-year event water surface top widths within the model.

6 Floodplain Evaluation

This project is not within a FEMA special flood hazard area (SFHA); see Appendix A for FIRM. The existing-project and expected proposed-project conditions were evaluated to determine whether the project would cause a change in flood risk.

6.1 Water Surface Elevations

The proposed project will eliminate backwater conditions at SR 308, so that the WSE immediately upstream will be reduced by the proposed crossing. The existing and proposed water surface profiles converge at station 6+70 and station 7+40, where the proposed WSE will be slightly greater than the existing WSE due to regrading of the channel. The downstream WSE will increase slightly immediately downstream of the culvert as the hydraulics of this crossing are restored to more natural conditions, as shown in Figure 58. WSE increases downstream of the crossing that will occur are due to reductions in outlet velocity and are not a result of fill from the project. These increases in WSE will be minor, up to 0.8 feet but typically between 0.1 and 0.2 feet (see Figure 59) and will not increase flood risk to surrounding properties or infrastructure due to the valley height (about 40 feet) being much greater than the increase in WSE. A flood risk assessment will be developed during later stages of the design.

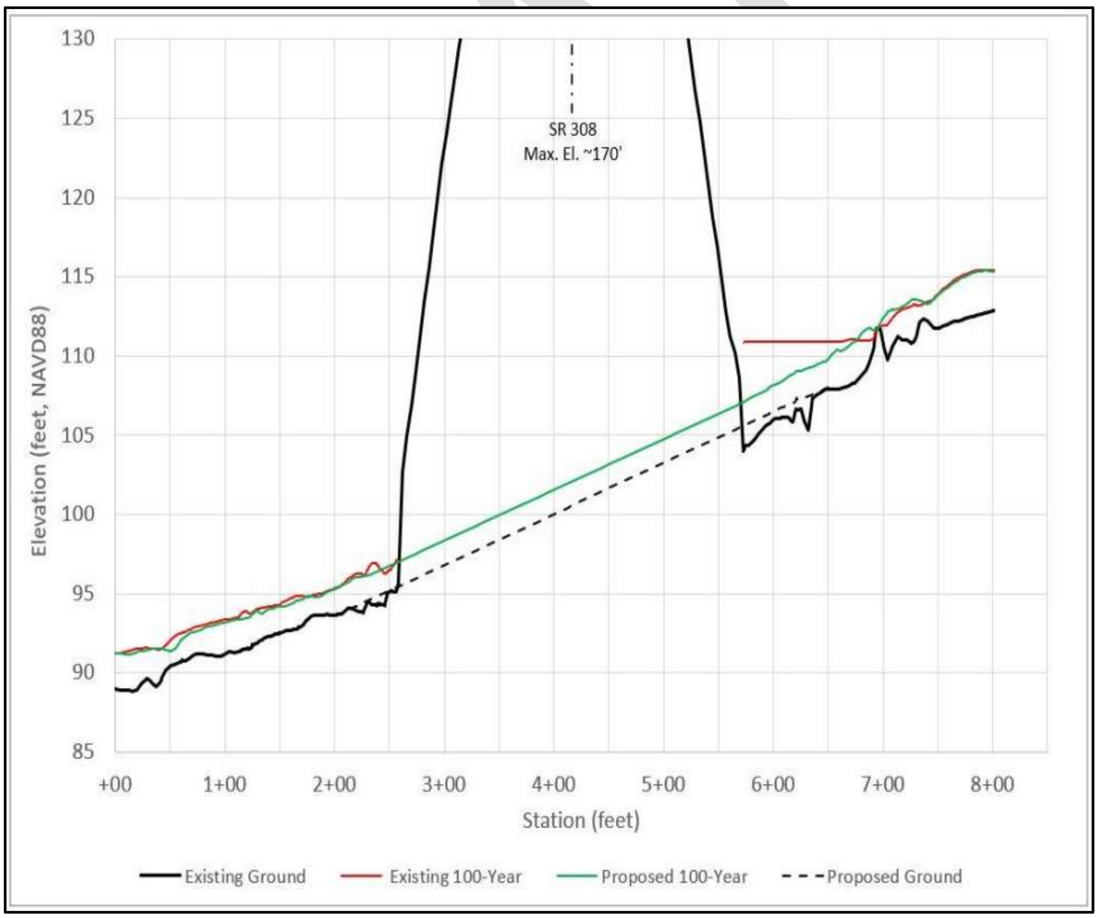

Figure 58: Existing- and proposed-conditions 100-year water surface profile comparison along proposed alignment

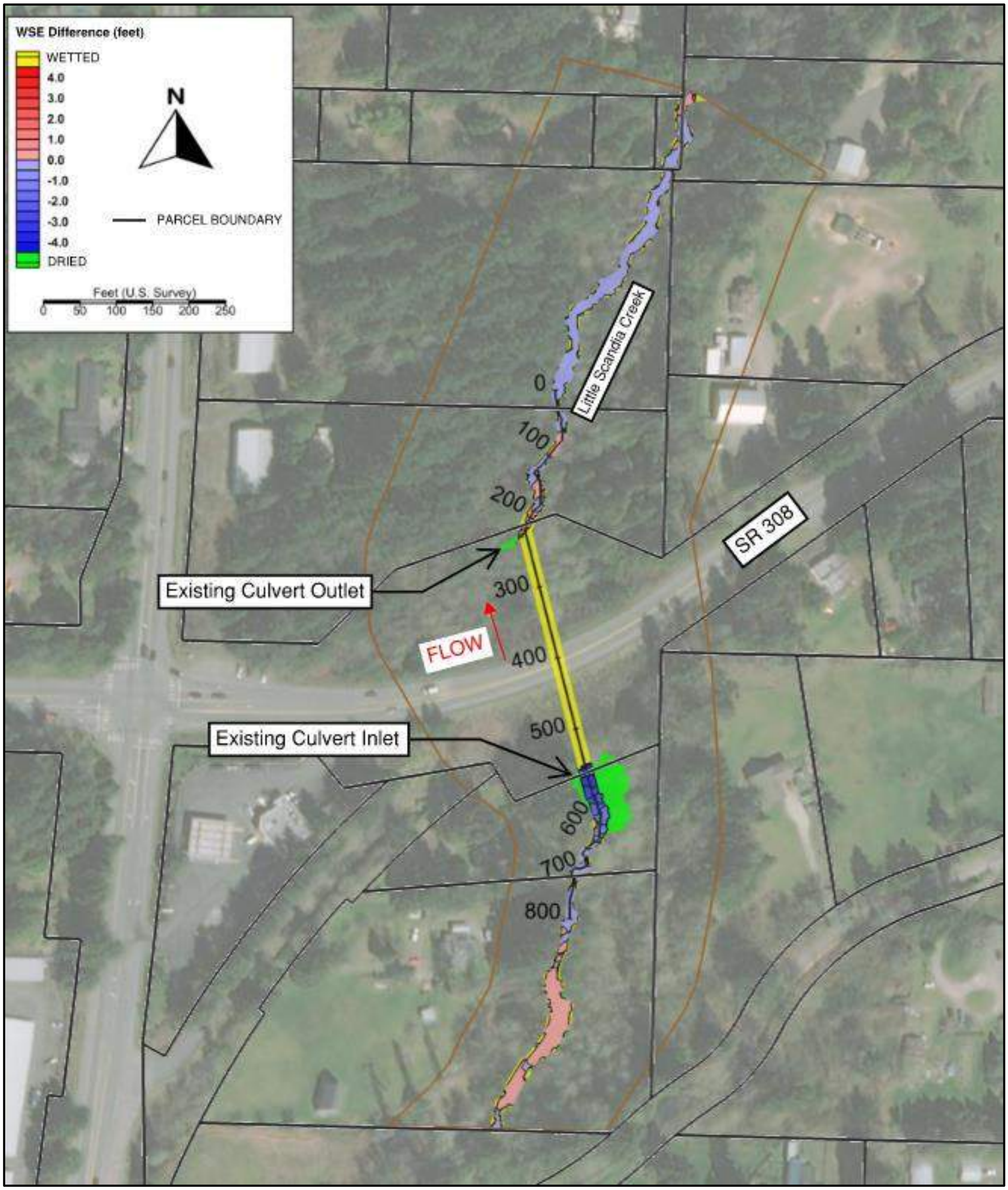

Figure 59: 100-year WSE change from existing to proposed conditions

7 Preliminary Scour Analysis

For this preliminary phase of the project, the risk for lateral migration, potential for long-term degradation and evaluation of preliminary total scour is based on available data, including but not limited to geologic and soil mapping as well as field measurements and observations. This evaluation is to be considered preliminary and is not to be taken as a final recommendation. The geotechnical scoping memo provided by WSDOT dated September 7, 2022, contained three soil borings used to inform this section.

Using the results of the hydraulic analysis (Section 5.4), based on the recommended minimum hydraulic opening (19 feet), and considering the potential for lateral channel migration, preliminary scour calculations for the scour design flood (2080 projected 100-year event, 127.0 cfs), and scour check flood (500-year event, 144.3 cfs) were performed following the procedures outlined in *Evaluating Scour at Bridges, HEC No. 18* (Arneson et al. 2012).

Scour components considered in the analysis include:

- Long-term degradation
- Contraction scour
- Local scour

In addition to the three scour components listed above, the potential for lateral migration was assessed to evaluate total scour at the proposed highway infrastructure. These various scour components will be discussed in the following sections. Other flow events, including the 2-year (25.1 cfs), 10-year (48.2 cfs), 50-year (65.5 cfs), and 100-year (82.1 cfs) were evaluated but were found to not produce the largest scour depths. Therefore, reporting on those events was not conducted. It was assumed without contacting WSDOT HQ Hydraulics, that the design of the proposed structure should account for the potential scour at the projected 2080 100-year flow event. A more refined analysis will be completed during final hydraulic design.

7.1 Lateral Migration

The geotechnical scoping memo for the site included information on three soil borings along the alignment of the existing crossing. The soil borings showed in-situ coarse-grained glacial deposits containing loose to medium dense silty sandy gravel soil to sandy gravel soil with a dense to very dense soil unit below comprised of similar sized particles. The soil borings confirmed the geologic and soil mapping data presented in Section 2.3. The geotechnical scoping memo determined that the soils are cohesionless and that the top soil layer has a medium (III) HEC-18 erodibility, while the deeper dense to very dense soil unit has a low (IV) HEC-18 erodibility. Therefore, there is risk of lateral migration on Little Scandia Creek as the upper soil unit may erode. The confined nature of the channel and tall valley walls will restrict large scale lateral migration, but the dynamic physical processes resulting from natural and constructed channel forcing elements, such as meander bars, will encourage small scale lateral migration of the main channel within the bottom of the current valley. Staff from WDFW and Suquamish tribal representatives expressed concern about channel migration due to a tight bend in the stream immediately upstream of the existing crossing which may cause large scour depths at the proposed structure inlet and toe of the proposed roadway embankment. To mitigate this risk, the channel was realigned to shift the crossing to a more central location within the historical valley. The realignment balances the risk of lateral migration and the loss of channel length.

The expected lateral migration over the life of the structure will be contained within the structure span because the minimum hydraulic width accounts for the meander belt width upstream and downstream of the crossing (see Section 4.2.2).

The Little Scandia Creek watershed upstream of SR 308 appears to have ample sediment supply due to the lack of both recent erosion and downcutting in the project area (see Section 2.7.4). Historical landslides within the watershed are confirmed by geologic mapping and by the geotechnical scoping memo, which list the presence of two unstable slopes along SR 308 within 1 mile of the existing crossing. Future slides within the watershed will provide additional sediment to the stream system. The long-term degradation potential at and upstream of the crossing will contribute to the ample sediment supply through the crossing and to the downstream reach. The potential for 7 feet of long-term degradation, as discussed in Section 7.2, will make the channel more confined and less likely to migrate laterally. As this is a long-term process, lateral migration remains a risk.

Scour calculations confirm that the existing sediment will mobilize and provide sediment continuity during high-flow events. The critical velocity index evaluation, including shear stress and velocity results of the existing and proposed hydraulic models contained in Appendix K, shows live bed scour conditions during flow events equal to and greater than the 10-year event. Live bed scour involves the sediment being replaced by upstream sediment at the end of the event. Flow events less than and equal to the 2-year event produce clear water scour which does not have sediment replenishment.

7.2 Long-term Degradation of the Channel Bed

The proposed channel alignment and slope closely mimic the existing conditions within the project limits, but the flatter channel slopes downstream of the proposed channel grading create a potential for long-term degradation. Section 2.7.4 discusses the vertical channel stability. The geotechnical scoping memo for this site identifies a dense to very dense glacial deposit (ESU 3b) beneath the crossing. The HEC-18 erodibility of this deposit is categorized as type IV (low erodibility). The soil boring on the upstream side of the crossing indicates that the top of the ESU 3b deposit begins at elevation 94 feet and has a depth of at least 25 feet, and the soil boring on the downstream end of the crossing indiciates that the top of the deposit begins at elevation 86 and has a depth of at least 25 feet. Based upon conversations with the WSDOT HQ Geotechnical scoping lead, the low erodibility deposit is assumed to parallel the existing ground surface. The top of the ESU 3b soil layer is shown in Figure 60 as a red dashed line. The 1.7 percent downstream watershed slope is believed to be stable based on its 2,000-foot-length shown on Figure 36 in Section 2.7.4 and lack of headcutting at existing downstream crossings of Little Scandia Creek at NW Linquist Lane, NW Blomster Way, Scandia Road NW, and a private driveway according to their WDFW Fish Passage and Diversion Screening Inventory Database reports. Therefore, the inflection point between the 1.7 and 2.3 percent channel slopes shown in Figure 60 is the assumbed base level control. Other base-level controls such as bedrock or knick points were not identified in the field nor in any supporting documentation. The low erodibility soil unit was not noted in the field, which supports the approxiate soil unit depth according to soil borings shown in Figure 60. The potential for long-term degradation is based upon topographic survey and LiDAR data used to construct the longitudinal profile of the stream (see Section 2.7.4) such as the extension of the downstrream 1.7 percent watershed slope to create the potential equilibrium slope shown in Figure 60. The maximum 7-foot potential long-term degradation at the crossing occurs at the upstream structure face.

Long-term degradation over the design life of the proposed structure should be verfied in the Final Hydraulic Design report.

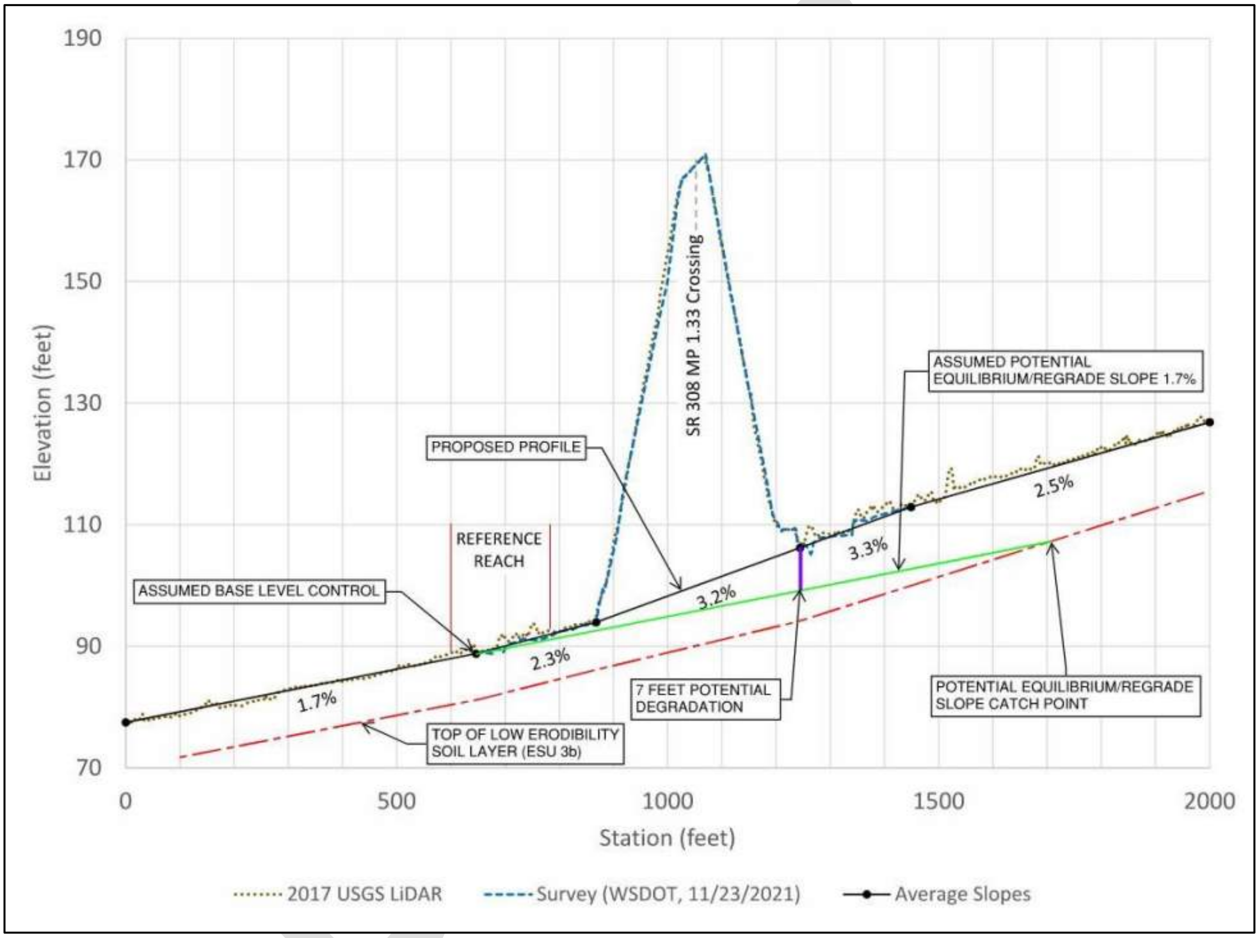

Figure 60: Potential long-term equilibrium slope at the proposed structure

7.3 Contraction Scour

The 2-year, 10-year, 50-year, 100-year, 2080 100-year, and 500-year events were evaluated for contraction scour. The analysis revealed depths of contraction scour ranging from 0.0 feet to 0.4 foot during all analyzed flows. A maximum depth of contraction scour of 0.5 foot was selected by conservatively rounding up the results of the 2080 100-year and 500-year events due to the sensitivity and accuracy of the scour equations (see Appendix K for output of the Federal Highway Administration's Hydraulic Toolbox Version 5.1.4 computer program (FHWA 2021) scour analysis). Appendix K also contains SMS Bridge Scour coverage figures showing the locations of the contracted sections, approach sections, and channel banks as well as the critical velocity index and velocity vector coverages.

A sensitivity analysis was performed using the 500-year event because the width transporting sediment in the contracted section is wider than the width transporting sediment in the approach section as seen in the critical velocity index (CVI) plots in Appendix K. The sensitivity analysis relocated the contracted section to a narrow portion of CVI just upstream of the proposed crossing and relocated the approach section to the area of widest CVI about 60 feet upstream from the initial location presented in Appendix K. The sensitivity analysis revealed a maximum contraction scour of about 0.1 feet and an abutment scour of about 0.2 feet during the 500-year event, which is less total scour than what was initially proposed and reported on in Appendix K. The sensitivity analysis confirmed that the initial contracted and approach sections produce reasonable and accurate scour depths.

Both clear water and live bed scour conditions were analyzed in Hydraulic Toolbox. The critical velocity index shows that clear water scour exists during the 2-year flow, while live bed scour exists during the 10-year and larger flows.

7.4 Local Scour

Local scour includes scour at bridge abutments, piers, and bends. A preliminary analysis of local scour was performed using the Federal Highway Administration's Hydraulic Toolbox Version 5.1.4 computer program (FHWA 2021).

7.4.1 Pier Scour

The crossing will not have piers and therefore pier scour was not calculated.

7.4.2 Abutment Scour

Abutment scour was estimated using the National Cooperative Highway Research Program (NCHRP) 24-20 approach for the scour design flood and scour check flood. The 2-year, 10-year, 50-year, 100-year, 2080 100-year, and 500-year events were evaluated for abutment scour. The hydraulic influence of the modeled vertical culvert walls is effectively the same as the hydraulic influence of vertical bridge abutments. Because main channel lateral migration is likely to occur within the proposed structure, abutment scour was evaluated relative to the thalweg depth and not necessarily the depth of flow at the abutment during the modeled flow scenarios.

Abutment scour equations estimate depths of scour of 0.0 feet at all evaluated flows. See Appendix K for the Hydraulic Toolbox scour analysis output and SMS Bridge Scour coverage figures showing the locations of the abutments and channel banks as well as the critical velocity index and velocity vector coverages.

7.4.3 Bend Scour

Bend scour was not quantified at this crossing given the lack of anticipated bends in the vicinity of the crossing.

7.5 Total Scour

Calculated depths of scour for the scour design flood and scour check flood at the proposed Little Scandia Creek crossing, as shown in the plans dated September 19, 2022, are provided in Table 16. HQ Hydraulics recommends that each infrastructure component be designed to account for the depths of scour provided in Table 16. Due to the sensitivity and accuracy of the scour equations, the calculated depths of scour were rounded up to the nearest 0.5 foot for reporting and design purposes. The local scour amount contained in Table 16 reflects the summation of pier, abutment, and bend scour, all of which are either not applicable to the crossing or equal to 0 feet.

Table 16: Scour analysis summary

Calculated scour for SR 308 MP 1.33 Little Scandia Creek		
	Scour design flood (2080 100-year)	Scour check flood (500-year)
Long-term degradation (feet) [a]	7.0	7.0
Contraction scour (feet)[a]	0.5	0.5
Abutment scour (feet) [a]	0.0	0.0
Total depth of scour (feet)[a]	7.5	7.5

[a]Scour depths are reported relative to the thalweg elevation.

8 Scour Countermeasures

Scour countermeasures are anticipated to be required at this crossing due to the potential for scour impacts to the roadway embankment. The scour countermeasures should accommodate the total scour depth, which is estimated to be 7.5 feet at this stage in design. Structure foundations will be designed below possible scour elevations and will not rely on scour countermeasures for protection. It is possible for the proposed structure type and geometry, such as the possible need for wingwalls, to provide the necessary scour countermeasures to protect the roadway embankment. If scour countermeasures are needed, they may not encroach within the minimum hydraulic opening. If LWM is placed within the structure at future design phases, scour countermeasures will be needed to protect against scour near the LWM pieces. Figure 61 shows an example of a scour countermeasure from the 2022 WSDOT *Hydraulics Manual* for crossings without calculated abutment scour. This figure serves as an example of the countermeasure geometry only and does not represent the possible structure type or geometry. The buried rock revetment scour countermeasure shown in Figure 61 could also be used outside of the structure to protect the roadway embankment.

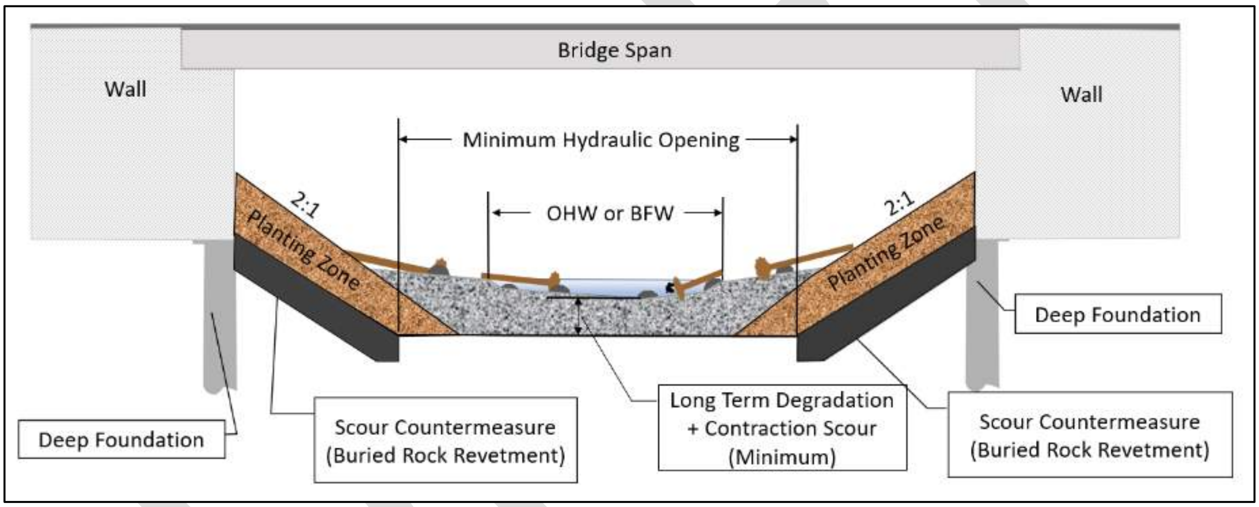

Figure 61: Potential scour countermeasure example

9 Summary

Table 17 presents a summary of the results of this PHD Report.

Table 17: Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	3,694 linear feet	2.1 Site Description
Bankfull width	Reference reach found?	Yes	2.7.1 Reference Reach Selection
	Design BFW	10.0 feet	2.7.2 Channel Geometry
	Concurrence BFW	10.0 feet	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	19.0 feet	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	1.9	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Complexity
Hydrology/design flows	100 yr flow	82.1 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr flow	127.0 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr used for design	Yes	3 Hydrology and Peak Flow Estimates
	Dry channel in summer	No	3 Hydrology and Peak Flow Estimates
Channel geometry	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	2.5%	2.6.2 Existing Conditions
	Reference reach	2.4%	2.7.1 Reference Reach Selection
	Proposed	3.2%	4.1.3 Channel Gradient
Hydraulic width	Existing	3.5 feet	2.6.2 Existing Conditions
	Proposed	19 feet	4.2.2 Hydraulic Width
	Added for climate resilience	No	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	2.0 feet	4.2.3 Vertical Clearance
	Required freeboard applied to 100 yr or 2080 100 yr	2080 100-year	4.2.3 Vertical Clearance
	Maintenance clearance	Required 6 feet	4.2.3 Vertical Clearance
	Low chord elevation	See link	4.2.3 Vertical Clearance
Crossing length	Existing	313.6 feet	2.6.2 Existing Conditions
	Proposed	296.0 feet	4.2.4 Hydraulic Length
Structure type	Recommendation	No	4.2.6 Structure Type
	Type	Not yet selected	4.2.6 Structure Type
Substrate	Existing	See link	2.7.3 Sediment
	Proposed	See link	4.3.1 Bed Material
	Coarser than existing?	No	4.3.1 Bed Material

Table 17: Report summary (continued)

Stream crossing category	Element	Value	Report location
Channel complexity	LWM for bank stability	No	4.3.2 Channel Complexity
	LWM for habitat	Yes	4.3.2 Channel Complexity
	LWM within structure	No	4.3.2 Channel Complexity
	Meander bars	11	4.3.2 Channel Complexity
	Boulder clusters	0	4.3.2 Channel Complexity
	Coarse bands	0	4.3.2 Channel Complexity
	Mobile wood	Yes	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	No	6 Floodplain Evaluation
	Lateral migration	No	2.7.5 Channel Migration
	Floodplain changes?	No	6 Floodplain Evaluation
Scour	Analysis	See link	7 Preliminary Scour Analysis
	Scour countermeasures	Determined at FHD	8 Scour Countermeasures
Channel degradation	Potential?	0 – 7 feet	7.2 Long-term Degradation of the Channel Bed
Channel degradation	Allowed?	Yes	7.2 Long-term Degradation of the Channel Bed

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Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix E: Manning's Calculations (Not used)

Appendix F: Large Woody Material Calculations

Appendix G: Future Projections for Climate-Adapted Culvert Design

Appendix H: SRH-2D Model Results

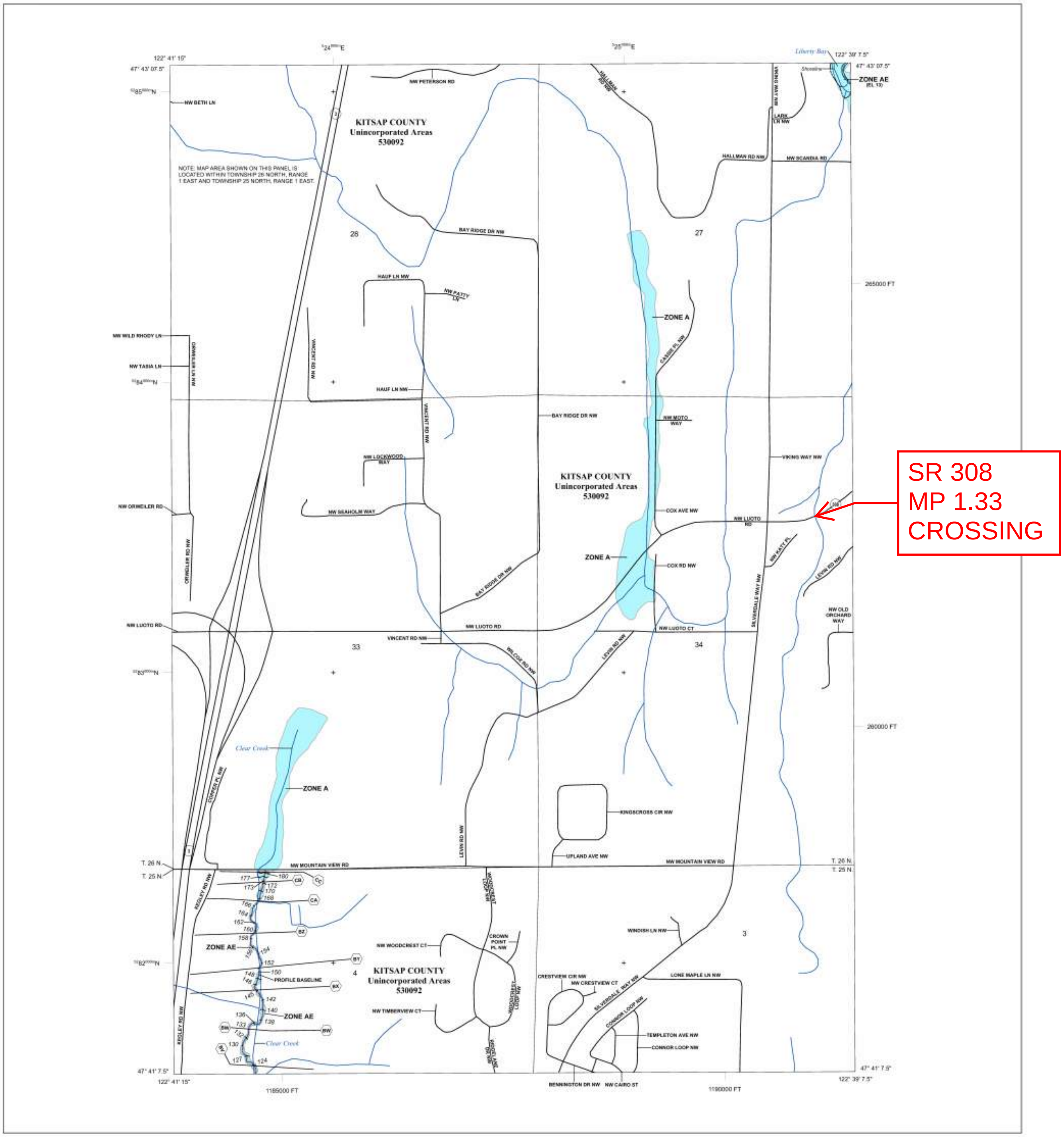
Appendix I: SRH-2D Model Stability and Continuity

Appendix J: Reach Assessment (Not used)

Appendix K: Scour Calculations (Preliminary)

Appendix L: Floodplain Analysis (FHD only)

Appendix A: FEMA Floodplain Map



FLOOD HAZARD INFORMATION

SEE FIS REPORT FOR ZONE DESCRIPTIONS AND INDEX MAP
THE INFORMATION DEPICTED ON THIS MAP AND SUPPORTING DOCUMENTATION ARE ALSO AVAILABLE IN DIGITAL FORMAT AT
HTTP://MSC.FEMA.GOV

SPECIAL FLOOD HAZARD AREAS		Without Base Flood Elevation (BFE) Zone A,V, A99
		With BFE or Depth Zone AE, AO, AH, VE, AR
		Regulatory Floodway
OTHER AREAS OF FLOOD HAZARD		0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile Zone X
		Future Conditions 1% Annual Chance Flood Hazard Zone X
		Area with Reduced Flood Risk due to Levee See Notes. Zone X
OTHER AREAS	NO SCREEN	Areas Determined to be Outside the 0.2% Annual Chance Floodplain Zone X
		Area of Undetermined Flood Hazard Zone D
GENERAL STRUCTURES		Channel, Culvert, or Storm Sewer
		Accredited or Provisionally Accredited Levee, Dike, or Floodwall
		Non-accredited Levee, Dike, or Floodwall
	(E) 18.2 / 17.5	Cross Sections with 1% Annual Chance Water Surface Elevation (BFE)
	(8)	Coastal Transect
		Coastal Transect Baseline
		Profile Baseline
		Hydrographic Feature
	513	Base Flood Elevation Line (BFE)
OTHER FEATURES		Limit of Study
		Jurisdiction Boundary

NOTES TO USERS

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To determine if flood insurance is available in the community, contact your Insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

Base map information shown on this FIRM was provided in digital format by Washington State GIS, Kitsap County GIS and Kitsap County Auditor and Elections.

SCALE

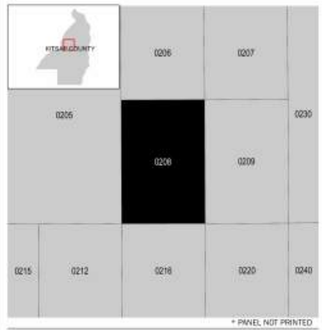
Map Projection:
NAD 1983 UTM Zone 10N
Western Hemisphere; Vertical Datum: NAVD 88

1 inch = 500 feet 1:6,000

0 500 1,000 2,000 Feet

0 125 250 500 Meters

PANEL LOCATOR



* PANEL NOT PRINTED

FEMA
National Flood Insurance Program

NATIONAL FLOOD INSURANCE PROGRAM
FLOOD INSURANCE RATE MAP

KITSAP COUNTY, WASHINGTON
AND INCORPORATED AREAS

PANEL 208 OF 525

Panel Contains:

COMMUNITY	NUMBER	PANEL	SUFFIX
KITSAP COUNTY	530092	0208	F

VERSION NUMBER
2.2.2.1

MAP NUMBER
53035C0208F

MAP REVISED
FEBRUARY 3, 2017

Appendix B: Hydraulic Field Report Form

WSDOT Hydraulics Section	Hydraulics Field Report	Project Number: Y-12554 – Task Order AC
	Project Name: Olympic Region GEC	Date: 11/29/2021
	Project Office: WSDOT HQ Hydraulics Office – Olympic Region	Time of Arrival: 9:30 AM
	Stream Name: Little Scandia Creek	Time of Departure: 11:30 AM
WDFW ID Number: 992008	Tributary to: Liberty Bay – Puget Sound	Weather: Partly Sunny, 55° F
State Route/MP: SR308 MP 1.33	Township/Range/Section/ ¼ Section: Township 26 North, Range 01 East, Section 35	Prepared By: Mike Rice
County: Kitsap	Purpose of Site Visit: Site Visit 2 – Stream Assessment and Project Complexity	WRIA: 15.0279

Meeting Location:
15244 Silverdale Way NW, Poulsbo, WA 98370

Attendance List:

Name	Organization	Role
Mike Rice	David Evans and Associates, Inc.	Lead PHD Author
Ryan Barkie	David Evans and Associates, Inc.	Junior Engineer/Modeler
Josh Owens	David Evans and Associates, Inc.	Geomorphologist
Micco Emeson	David Evans and Associates, Inc.	Engineer
Rachel Krulc	David Evans and Associates, Inc.	Junior Engineer
Atalia Raskin	David Evans and Associates, Inc.	Engineer

Bankfull Width:

Two bankfull width (BFW) measurements were taken within the reference reach (BFW-1 and BFW-2), located upstream of the existing barrier. The average of these measurements is 9.5 feet. Three BFW measurements were taken outside the reference reach (BFW-3, BFW-4, and BFW-5), located downstream of the existing barrier. The average of these measurements is 9.0 feet. See Figure 1 for BFW measurement locations.

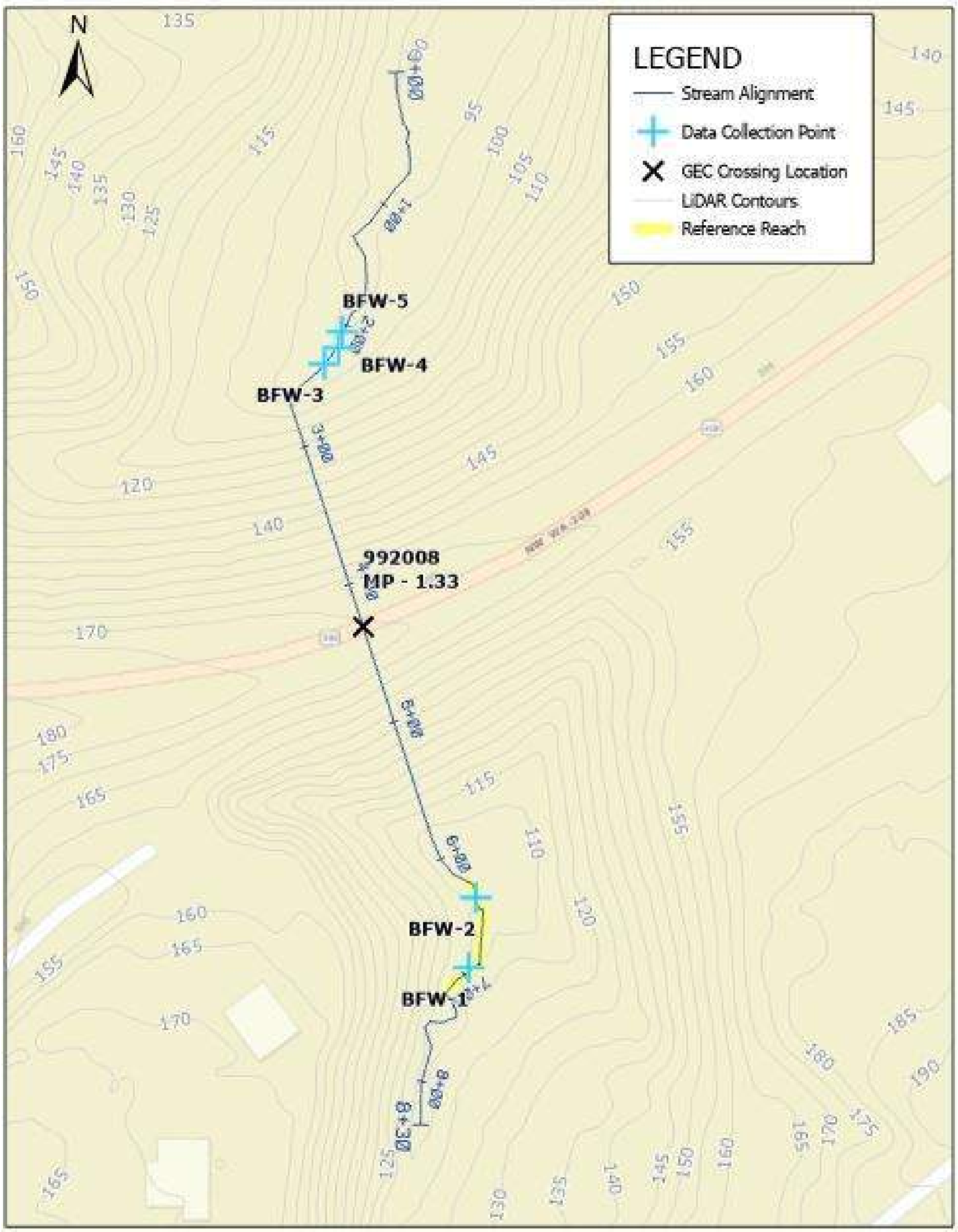


Figure 1. Location of BFW Measurements

*BFW-1 was measured within the reference reach 109 feet upstream of the SR308 barrier (*Figure 2*). The measured BFW was 8.0 feet.*

Figure 2. BFW-1 measurement of 8.0 feet

*BFW-2 was measured within the reference reach 51 feet upstream of the SR 308 barrier (*Figure 3*). The measured BFW was 11.0 feet.*

Figure 3. BFW-2 measurement of 11.0 feet.

*BFW-3 was measured outside the reference reach 37 feet downstream of the SR 308 barrier (*Figure 4*). The measured BFW was 7.0 feet.*

Figure 4. BFW-3 measurement at 7.0 feet.

*BFW-4 was measured outside the reference reach 52 feet downstream of the SR 308 barrier (*Figure 5*). The measured BFW was 11.0 feet.*


Figure 5. BFW-4 measurement at 11.0 feet.

*BFW-5 was measured outside the reference reach 63 feet downstream of the SR 308 barrier (*Figure 6*). The measured BFW was 9.0 feet.*

Figure 6. BFW-5 measured at 9.0 feet.

Reference Reach:

*The reference reach is a 90-foot segment of the stream that begins approximately 40 feet upstream of the barrier inlet, extending to a distance approximately 130 feet upstream of the barrier inlet. There was no evidence of scour or deposition at the upstream end of the culvert indicating that the culvert is not capacity limited, and there is little upstream influence caused by the culvert (*Figure 7*). The reference reach is moderately confined, having steep hillslopes on either side of a narrow overbank area. At the upstream end of the reference reach the channel becomes more confined with limited overbank area. The overbank areas are readily accessible during flood events. The reference reach channel slope is approximately 2.9% based on available survey data. The riparian buffer is well established with ferns and other vegetation (*Figure 8*). There is an obstruction within the channel in the reference reach. The channel flows over and through a small obstruction between two trees (Figure 10) and there is a drop over the obstruction of about 2 feet. Upstream of this area the channel is flatter at 2% slope measured with a clinometer and straighter than the reference reach downstream of the obstruction that was estimated to be 3% slope measured with a clinometer.*

*The channel bed of the reference reach consists of fine gravels to cobbles with a few locations with fines and sand. Large boulders are present as well. Sandy depositional areas were observed at the channel fringe in locations where eddies are likely to form during high flows due to obstructions from trees and wood material (*Figure 10*). A pool has formed downstream of this tree that is about 1.5 feet deep and 15 feet wide. The coarse bed material created a pool-*

riffle morphology, however in the absence of large wood or other channel obstructions the pools were shallow with faster flow velocities that did not allow sand and fines to deposit.

Figure 7. Barrier inlet


Figure 8. Channel overbanks and riparian habitat


Figure 9. Channel obstruction upstream of reference reach

Figure 10. Large pool adjacent to tree with sand and fines

The channel downstream of the barrier may be suitable for a reference reach and has a flatter slope of 1% measured with a clinometer than the channel upstream of the barrier. The channel cross sectional geometry and bankfull width is consistent upstream and downstream of the barrier, however the downstream channel is straighter and more incised than the upstream channel, therefore the upstream channel is the preferred reference reach. There was also evidence of scour, approximately 8 inches deep, directly downstream of the barrier outlet (Figure 11).

Figure 11. Barrier outlet with scour

Data Collection:

Data was collected by staff engineers from David Evans and Associates, Inc. on November 29th, 2021. The field crew included the lead author for the PHD at this site, both junior and senior engineers with experience in Fish Passage projects, and a Geomorphologist.

The upstream end of the site was visited first. Observations were recorded, including two pebble counts and three BFW measurements. The natural conditions of the upstream reflected an appropriate reference reach. Next, the downstream side of the culvert was visited. A single pebble count and three BFW measurement were recorded downstream.

Observations:

The site visit occurred during winter baseflow conditions. The barrier inlet was mostly clear of debris and blockage with sand and pebble deposits directly upstream of the barrier. The barrier outlet flows into a small scour pool immediately downstream of the outlet. The barrier was installed with a moderate slope and does not appear to limit water or sediment capacity.

The channel is moderately confined with steep hillslopes on either side. In the vicinity of the culvert there is a wider section of overbank within the reference reach. The channel is not incised, and the overbanks are readily accessible *during flood flows. The channel exhibits some meandering but generally has low sinuosity. Along the upstream portion of the channel, an existing unidentifiable water type valve and vault are present adjacent to the channel (*Figure 12*). A ditch along the embankment slope appears to convey roadway runoff just upstream of the culvert (*Figure 13*). Along the downstream portion of the channel, a rock wall bounds the channel along one edge of the barrier outlet (*Figure 14*).*

There was no large wood in the channel except for isolated live trees. The culvert appears to be steeper than the stream channel indicated that the stream was realigned and shortened through the culvert. The culvert may have to be realigned to provide an acceptable slope for fish passage, which would also require channel realignment and grading. The original highway alignment was along NW Katy Place and was realigned to the existing alignment, which increased the roadway fill and potentially changed the culvert from the original alignment.

Figure 12. Unidentified vault adjacent to upstream channel

Figure 13. Ditch flow to upstream end of barrier

Figure 14. Rock wall along edge of channel at barrier outlet

The channel bed is dominated by coarse material ranging from fine gravels to cobbles. These materials create a low-amplitude pool-riffle sequence where the flow over the riffles is less than 6 inches deep and the flow through the pools is less than 12 inches deep. Because of the shallow pools the bed material is relatively consistent throughout the reach and there is not much channel complexity. There is no evidence of recent erosion in the form of downcutting or lateral migration indicating that the channel is vertically and laterally stable with this simple geometry. There are locations that are influenced by single pieces of large wood or trees (**Error! Reference source not found.**e 11) that have locally created greater channel complexity in the form of deeper pools, sand deposition, and bank undercutting. Increasing the amount of wood material in the channel will improve habitat but is not necessary for channel stability.

Pebble Counts:

Three Wolman Pebble Counts (PC) were conducted at this site. See Figure 15*for PC locations.*

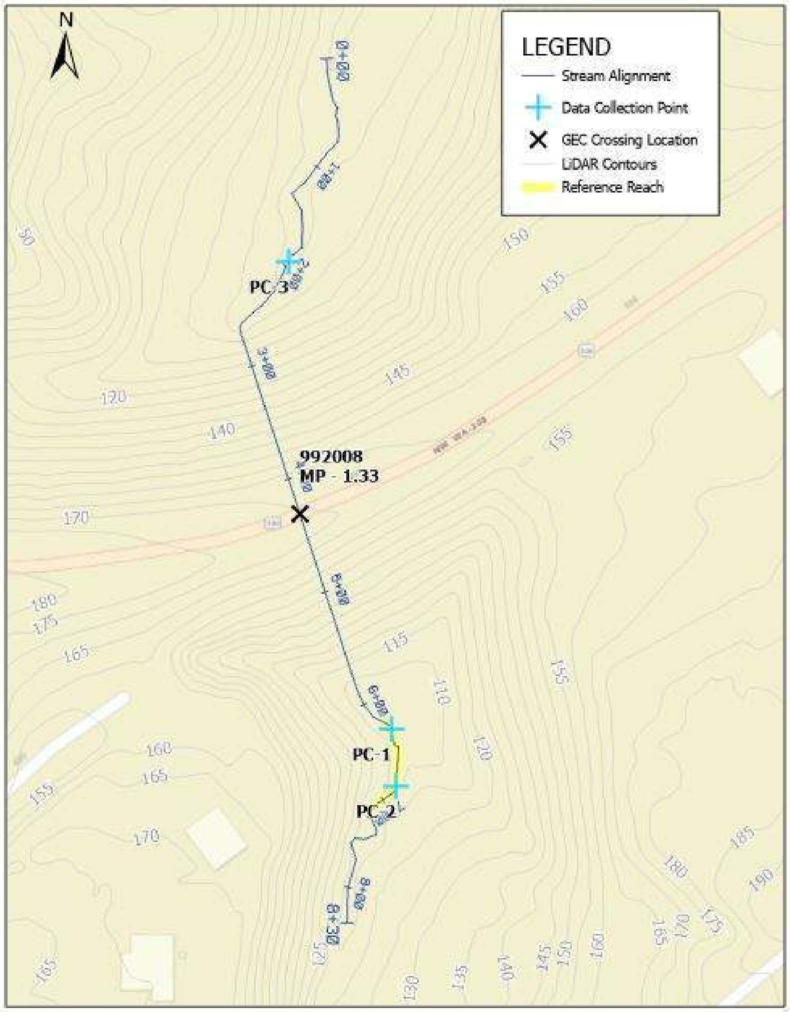


Figure 15. Pebble Count Locations

PC-1 was conducted along a length of stream approximately 46 feet upstream of the existing barrier inlet. The sediment here consisted of coarse sands, gravels, and small cobbles 90 millimeters or less. See Figure 16*.*

Figure 16. PC-1 sediment with gravelometer reference

PC-2 was conducted along a length of stream approximately 99 feet upstream of the existing barrier inlet. The sediment here consistent of coarse sands, gravels, and small cobbles 128 millimeters or less. The pebble count locations within the reference reach were taken over a distance of approximately 50 feet that exhibited faster flow and few fines, therefore this pebble count represents the upper size limit of coarse material that could be mobilized by the stream without the influence of wood material or other potential grade controls. In slack water areas such as pools or eddies, this material will become overtopped with sand as was observed locally within the reach. See Figure 17*.*

Figure 17. PC-2 sediment with gravelometer reference

PC-3 was conducted along a length of stream approximately 72 feet downstream of the culvert outlet outside of the reference reach. The PC was fairly consistent with the PCs conducted upstream of the barrier. See Figure 18*.*

Figure 18. PC-3 sediment with gravelometer reference

Photos:
Any relevant photographs placed here with descriptions.

Samples:	
Work within the wetted perimeter may only occur during the time periods authorized in the APP ID 21036 entitled "Allowable Freshwater Work Times May 2018". Work outside of the wetted perimeter may occur year-round. APPS website: https://www.govonlinesaas.com/WA/WDFW/Public/Client/WA_WDFW/Shared/Pages/Main/Login.aspx	
Were any sample(s) collected from below the OHWM?	*No ☐ If no, then stop here.*
	Yes ☒ If yes, then fill out the proceeding section for each sample.

Sample #:	Work Start:	Work End:	Latitude:	Longitude:
PC-1 and PC-2	11/29/21 9:30 AM	11/29/21 11:30 AM	XXXXX	XXXXX

Summary/description of location:

Three Wolman Pebble Counts (PC) were taken at this location. Two PCs were conducted upstream of the culvert outlet, one approximately 46 feet and one 99 feet upstream of the culvert inlet. Another PC was conducted approximately 72 feet downstream of the culvert outlet.

Description of work below the OHWL:

Work within the OHW included Wolman Pebble Counts which consists of walking along the streambed to collect 100 random samples of sediment. These samples are then measured in-situ to determine the gradation of the existing streambed sediment. After being measured the samples are returned to the stream.

Description of problems encountered:

No problems were encountered.

Concurrence Meeting	Date: 2/3/22	Time of Arrival: 10:30
Prepared By: Mike Rice	Weather: Mostly Cloudy	Time of Departure: 12:00

Attendance List:

Name	Organization	Role
Mike Rice	David Evans & Associates	Lead Engineer
Amber Martens	WDFW	
Nam Siu	WDFW	
Shawn Stanley	WDFW	
Damon Romero	WSDOT	
Cade Roler	WSDOT	
Kate Fauver	WSDOT	
Heather Pittmans	WSDOT	
Hunter Henderson	WSDOT	
Alison O’Sullivan	Suquamish Tribe	

Bankfull Width:

*Design team and comanagers measured eight BFW measurements. Three BFWs were measured upstream of the crossing (*Figure 19 *and* Figure 20*), and 5 BFWs were measured downstream of the crossing (*Figure 21*,* Figure 22*, and* Figure 23*). Given the crossing is in a transitional section between steeper upstream slopes and flatter downstream slopes, comanagers requested the design team to use an average of both upstream and downstream BFW. Team agreed to use a BFW of 10’ for design.*

Reference Reach:

Design team and comanagers reviewed LiDAR data on-site and determined that the initial reference reach is likely impacted by a historic landslide. The reference reach was shifted to downstream of the culvert from approximately 150’ to 350’ (beyond the survey limits) of the crossing. This has a flatter slope, 2.5-2.7%, relative to the upstream area, 2.9-3.5%. Comanagers stated that they would be ok with not meeting slope ratio requirements and that the proposed crossing should be kept as flat as possible with regrading impacts extending upstream as much as possible.

Observations:
*Juvenile coho were observed downstream of the crossing. Two private water supply pumps, one upstream and one downstream of the crossing, were observed adjacent to the creek. A small dam seems to have been constructed near the downstream supply line to impound water (*Figure 24*). LiDAR data seems to indicate that the upstream area is impacted by a historic landslide.*
Photos:

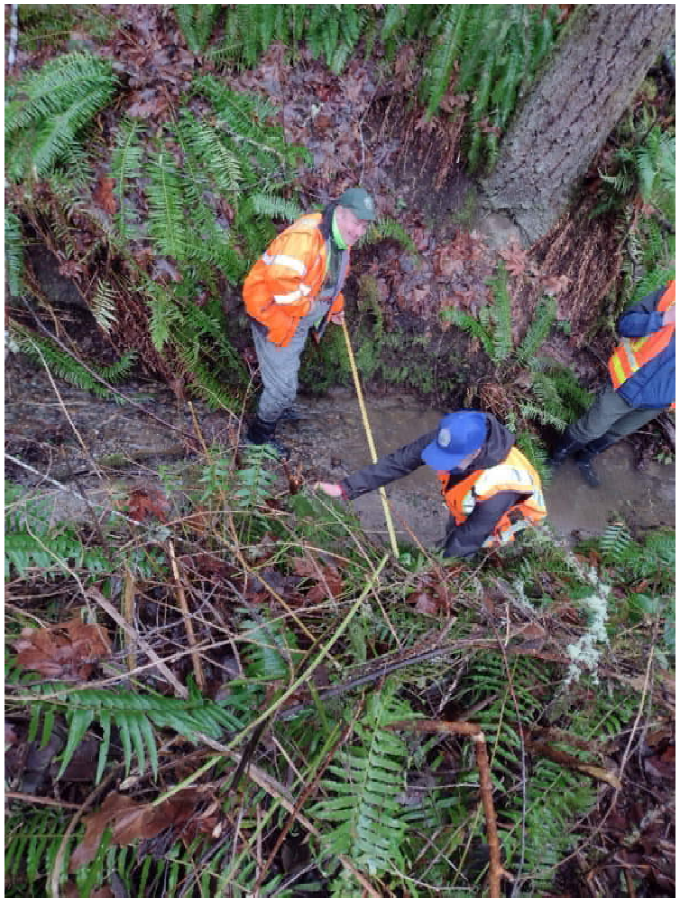


Figure 19. Added upstream BFW measurement of 7.0'

Figure 20. Added upstream BFW measurement of 7.6'

Figure 21. Added downstream BFW measurement of 10.5'

Figure 22. Added downstream BFW measurement of 8.5'


Figure 23. Added downstream BFW measurement of 9.0'


Figure 24. Private water supply line downstream of crossing

Fish Passage Project Site Visit - Determining Project Complexity

PROJECT NAME:	**WSDOT OLYMPIC REGION GEC**
WDFW SITE ID:	**992008**
STATE ROUTE/MILEPOST:	**SR308 MP1.33**
SITE VISIT DATE:	**11/29/21**
ATTENDEES:	**Micco Emeson (DEA), Josh Owens (DEA), Mike Rice (DEA), Atalia Raskin (DEA), Ryan Barkie (DEA), Rachel Krulc (DEA)**
ANTICIPATED LEVEL OF PROJECT COMPLEXITY - Low/Medium/High (*additional considerations or red flags may trigger the need for new discussions*):	**Medium-Low to Medium. Primarily low complexity, but there will be some channel regrading to account for the anticipated slope changes between existing and proposed structures. Other items adding to complexity include depth of fill above the barrier (approx. 60' of fill), presence of utilities above the barrier, possible need to realign culvert to help with anticipated steep slope, and slope ratio.**
IN WATER WORK WINDOW	**To be provided by WDFW**

The following elements of projects should be discussed before the production of a Preliminary Hydraulic Design by members of WSDOT and WDFW to identify the level of complexity for each site, and corresponding communication and review. While certain elements may be categorized as indicators of a low/medium/high complexity project, these are only suggestions, and newly acquired information may change the level of complexity during a project. The ultimate documentation category for a given site is up to both WSDOT and WDFW, considering both site characteristics and synergistic effects.

Discuss the following elements as they apply to the project. Rank each element as low, medium, or high in complexity. If there are items that need follow-up, mark those and provide a brief description in the column labeled, "Is follow up needed on this item?" The assigned level of complexity determines the appropriate agreed upon review from WDFW (see review parameters here (*final full doc goes here*)). Ultimately, WSDOT needs to acquire an HPA from WDFW for fish passage projects and the agreed upon communication and review of project elements will contribute to efficiencies in the permitting process.

Fish Passage Project Site Visit - Determining Project Complexity

Project Elements (anticipated)	Low Complexity	Medium Complexity	High Complexity	Is follow up needed on this item?
Stream grading		✓		Extg. rock wall at d/s end. Steep barrier may extend limits of regrading to tie into extg.
Risk of degradation/aggradation	✓			Some minor degradation noted.
Channel realignment		✓		Channel realignment may be necessary to catch existing grade if barrier is flattened.
Expected stream movement	✓			No significant channel movement is expected.
Gradient		✓		Existing barrier is at approx. 2.7% slope.
Potential for backwater impacts	✓			No existing backwater and no backwater impacts are expected.
Meeting requirements for freeboard	✓			Sufficient fill depth to meet freeboard requirements.
Stream size, and Bankfull Width	✓			Stream size is medium (<40 cubic feet per second), with BFW of approx. 9.5'.
Slope ratio		✓		Upstream slope and barrier slope are 2-3% while d/s slope is approx. 1%.
Sediment supply	✓			No supply or transport issues expected.
Meeting stream simulation	✓			No anticipated issues with meeting stream simulation.
Channel confinement		✓		Channel is somewhat confined u/s of survey limits and on the d/s side.
Geotech or seismic considerations	✓			None expected.
Tidal influence	✓			No tidal influence at this site. Channel thalweg elev > 25'
Alluvial fan	✓			Site is not within an alluvial fan.
Fill depth above barrier		✓		Significant fill in excess of approx. 60'.
Presence of other nearby barriers	✓			No barriers close enough to impact structure.
Presence of nearby infrastructure		✓		Adjacent utilities (sanitary force main, naval fiber optics) and extg. adjacent water infrastructure.
Need for bank protection	✓			None expected.
Floodplain utilization ratio	✓			Channel is mostly confined except immediately u/s of barrier with some overbank area.

Other: NONE				

Appendix C: Streambed Material Sizing Calculations

Summary - Stream Simulation Bed Material Design

Project:	Preliminary Hydraulic Design for Little Scandia Creek at SR308 MP 1.33 (ID 992008)
By:	Chad Booth, PE

Design Gradation:

Location:	Proposed Gradation			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.5	0.2	0.1	0.01
in	6.0	2.0	0.8	0.1
mm	152	52	21	3

Gradation from survey:

Location:	PC1			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.4	0.1	0.06	0.02
in	5.0	1.5	0.7	0.2
mm	128	38	17	5

Gradation from survey:

Location:	PC2			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.4	0.1	0.04	0.0003
in	5.0	1.7	0.5	0.004
mm	128	43	13	0.1

Gradation from survey:

Location:	PC3			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.3	0.1	0.06	0.0003
in	3.5	1.5	0.7	0.004
mm	90	38	18	0.1

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size		Streambed	Streambed Cobbles					Streambed Boulders			D_{size}
[in]	[mm]	Sediment	4"	6"	8"	10"	12"	12"-18"	18"-28"	28"-36"	
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				100.0
6.0	152			100	80	68	57				100.0
5.0	127			80	68	57	45				98.0
4.0	102		100	71	57	45	39				97.1
3.0	76.2		80	63	45	38	34				94.3
2.5	63.5	100	65	54	37	32	28				91.9
2.0	50.8	92.5	50	45	29	25	22				83.5
1.5	38.1	79	35	32	21	18	16				70.1
1.0	25.4	66	20	18	13	12	11				56.6
0.50	12.7	48	5	5	5	5	5				39.4
0.19	4.75	29									23.2
0.02	0.425	10									8.0
0.003	0.0750	5									4.0
% per category		80	10	10	0	0	0	0	0	0	--> 100%
% Cobble & Sediment		80.0	10.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0%

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings

U.S. Department of Agriculture, Forest Service, National Technology and Development Program, August 2008.

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

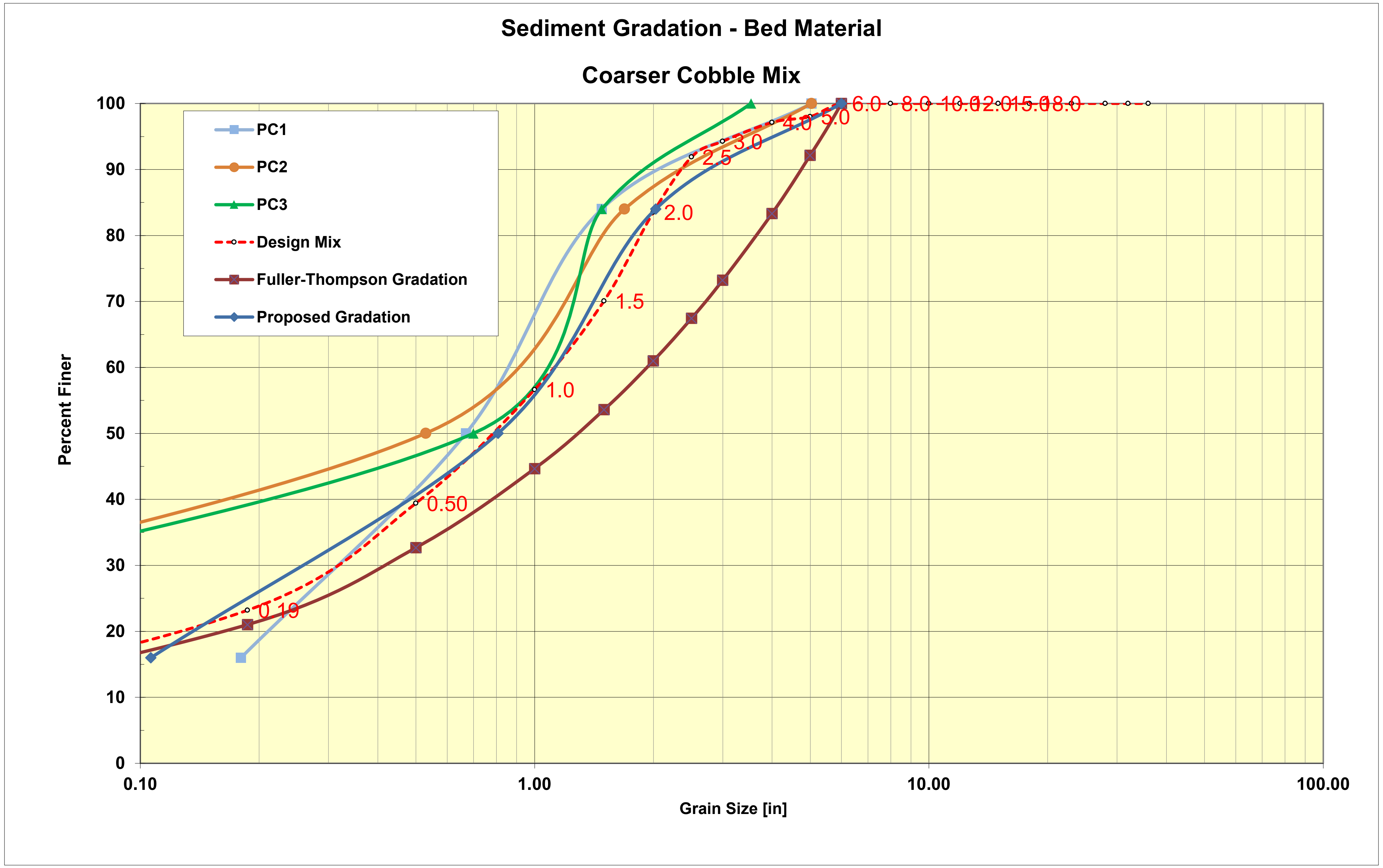
Slopes less than 5%

Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.047	dimensionless Shields parameter for D50, use table E.1 of USFS manual
		or assume 0.045 for poorly sorted channel bed

Flow	2-Year	10-Year	25-Year	50-Year	100-Year	500-Year
Average Modeled Shear Stress (lb/ft^2)	1.10	1.60	1.80	1.90	2.10	2.70
τ_{ci}						
1.01	Motion	Motion	Motion	Motion	Motion	Motion
0.98	Motion	Motion	Motion	Motion	Motion	Motion
0.94	Motion	Motion	Motion	Motion	Motion	Motion
0.89	Motion	Motion	Motion	Motion	Motion	Motion
0.82	Motion	Motion	Motion	Motion	Motion	Motion
0.78	Motion	Motion	Motion	Motion	Motion	Motion
0.73	Motion	Motion	Motion	Motion	Motion	Motion
0.69	Motion	Motion	Motion	Motion	Motion	Motion
0.65	Motion	Motion	Motion	Motion	Motion	Motion
0.59	Motion	Motion	Motion	Motion	Motion	Motion
0.56	Motion	Motion	Motion	Motion	Motion	Motion
0.52	Motion	Motion	Motion	Motion	Motion	Motion
0.48	Motion	Motion	Motion	Motion	Motion	Motion
0.46	Motion	Motion	Motion	Motion	Motion	Motion
0.43	Motion	Motion	Motion	Motion	Motion	Motion
0.39	Motion	Motion	Motion	Motion	Motion	Motion
0.35	Motion	Motion	Motion	Motion	Motion	Motion
0.28	Motion	Motion	Motion	Motion	Motion	Motion

D50	0.81	in
	0.07	ft
	20.5	mm



Fuller-Thompson Gradation	
Dmax =	6
D[in]	
12.000	136.60
10.000	125.84
8.000	113.82
6.000	100.00
5.000	92.12
4.000	83.32
3.000	73.20
2.500	67.44
2.000	61.00
1.500	53.59
1.000	44.65
0.500	32.69
0.187	21.00
0.017	7.09
0.003	3.25

Summary - Stream Simulation Meander Bar Tail Design

Project:	**Preliminary Hydraulic Design for Little Scandia Creek at SR308 MP 1.33 (ID 992008)**
By:	**Chad Booth, PE**

Design Gradation:

Location:	Proposed Gradation			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	**0.7**	**0.5**	**0.2**	**0.03**
in	**8.0**	**5.7**	**2.0**	**0.4**
mm	**203**	**144**	**51**	**10**

Gradation from survey:

Location:	PC1			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	**0.4**	**0.1**	**0.06**	**0.02**
in	**5.0**	**1.5**	**0.7**	**0.2**
mm	**128**	**38**	**17**	**5**

Gradation from survey:

Location:	PC2			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	**0.4**	**0.1**	**0.04**	**0.0003**
in	**5.0**	**1.7**	**0.5**	**0.004**
mm	**128**	**43**	**13**	**0.1**

Gradation from survey:

Location:	PC3			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	**0.3**	**0.1**	**0.06**	**0.0003**
in	**3.5**	**1.5**	**0.7**	**0.004**
mm	**90**	**38**	**18**	**0.1**

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size		**Streambed Sediment**	**Streambed Cobbles**					**Streambed Boulders**			**D_{size}**
[in]	**[mm]**		**4"**	**6"**	**8"**	**10"**	**12"**	**12"-18"**	**18"-28"**	**28"-36"**	
36.0	**914**									**100**	**100.0**
32.0	**813**									50	**100.0**
28.0	**711**								**100**		**100.0**
23.0	**584**								50		**100.0**
18.0	**457**							**100**			**100.0**
15.0	**381**							50			**100.0**
12.0	**305**						**100**				**100.0**
10.0	**254**					**100**	**80**				**100.0**
8.0	**203**				**100**	**80**	68				**100.0**
6.0	**152**			**100**	**80**	68	57				**86.6**
5.0	**127**			**80**	68	57	**45**				**78.8**
4.0	**102**		**100**	71	57	**45**	39				**71.0**
3.0	**76.2**		**80**	63	**45**	38	34				**63.2**
2.5	**63.5**	**100**	65	54	37	32	28				**57.8**
2.0	**50.8**	**92.5**	50	**45**	29	25	22				**50.0**
1.5	**38.1**	79	**35**	32	21	18	16				**40.2**
1.0	**25.4**	**66**	20	18	13	12	11				**30.5**
0.50	**12.7**	**48**	**5**	**5**	**5**	**5**	**5**				**19.2**
0.19	**4.75**	29									**9.6**
0.02	**0.425**	**10**									**3.3**
0.003	**0.0750**	**5**									**1.7**
% per category		**33**	**0**	**0**	**67**	**0**	**0**	**0**	**0**	**0**	*--> 100%*
% Cobble & Sediment		**33.0**	**0.0**	**0.0**	**67.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	*100.0%*

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

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U.S. Department of Agriculture, Forest Service, National Technology and Development Program, August 2008.

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

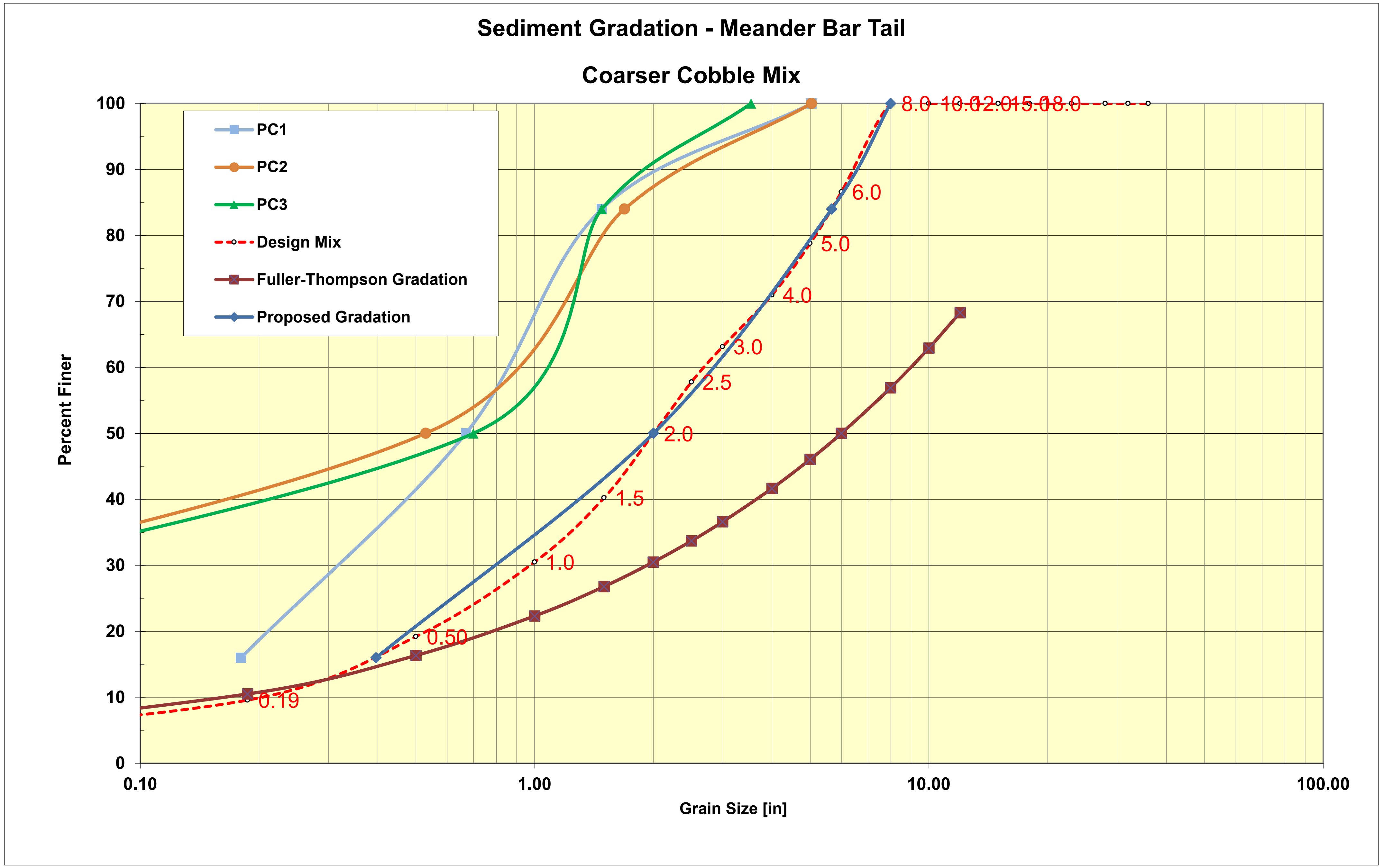
Slopes less than 5%

Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.05	dimensionless Shields parameter for D50, use table E.1 of USFS manual
		or assume 0.045 for poorly sorted channel bed

Flow	2-Year	10-Year	25-Year	50-Year	100-Year	500-Year
Average Modeled Shear Stress (lb/ft^2)	1.10	1.60	1.80	1.90	2.10	2.70
τ_{ci}						
2.04	No Motion	No Motion	No Motion	No Motion	Motion	Motion
1.97	No Motion	No Motion	No Motion	No Motion	Motion	Motion
1.89	No Motion	No Motion	No Motion	Motion	Motion	Motion
1.78	No Motion	No Motion	Motion	Motion	Motion	Motion
1.65	No Motion	No Motion	Motion	Motion	Motion	Motion
1.57	No Motion	Motion	Motion	Motion	Motion	Motion
1.47	No Motion	Motion	Motion	Motion	Motion	Motion
1.39	No Motion	Motion	Motion	Motion	Motion	Motion
1.30	No Motion	Motion	Motion	Motion	Motion	Motion
1.19	No Motion	Motion	Motion	Motion	Motion	Motion
1.13	No Motion	Motion	Motion	Motion	Motion	Motion
1.05	Motion	Motion	Motion	Motion	Motion	Motion
0.97	Motion	Motion	Motion	Motion	Motion	Motion
0.92	Motion	Motion	Motion	Motion	Motion	Motion
0.86	Motion	Motion	Motion	Motion	Motion	Motion
0.79	Motion	Motion	Motion	Motion	Motion	Motion
0.70	Motion	Motion	Motion	Motion	Motion	Motion
0.56	Motion	Motion	Motion	Motion	Motion	Motion

D50	2.00	in
	0.17	ft
	50.9	mm



Fuller-Thompson Gradation	
Dmax =	28
D[in]	
12.000	68.30
10.000	62.92
8.000	56.91
6.000	50.00
5.000	46.06
4.000	41.66
3.000	36.60
2.500	33.72
2.000	30.50
1.500	26.79
1.000	22.32
0.500	16.34
0.187	10.50
0.017	3.54
0.003	1.62

Summary - Stream Simulation Meander Bar Head Design

Project:	Preliminary Hydraulic Design for Little Scandia Creek at SR308 MP 1.33 (ID 992008)
By:	Chad Booth, PE

Design Gradation:

Location:	Proposed Gradation			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	1.5	1.3	1.0	0.05
in	18.0	16.1	12.0	0.5
mm	457	408	305	14

Gradation from survey:

Location:	PC1			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.4	0.1	0.06	0.02
in	5.0	1.5	0.7	0.2
mm	128	38	17	5

Gradation from survey:

Location:	PC2			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.4	0.1	0.04	0.0003
in	5.0	1.7	0.5	0.004
mm	128	43	13	0.1

Gradation from survey:

Location:	PC3			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.3	0.1	0.06	0.0003
in	3.5	1.5	0.7	0.004
mm	90	38	18	0.1

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size		Streambed	Streambed Cobbles					Streambed Boulders			D_{size}
[in]	[mm]	Sediment	4"	6"	8"	10"	12"	12"-18"	18"-28"	28"-36"	
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			75.0
12.0	305						100				50.0
10.0	254					100	80				46.0
8.0	203				100	80	68				43.7
6.0	152			100	80	68	57				41.3
5.0	127			80	68	57	45				39.0
4.0	102		100	71	57	45	39				37.9
3.0	76.2		80	63	45	38	34				36.7
2.5	63.5	100	65	54	37	32	28				35.6
2.0	50.8	92.5	50	45	29	25	22				32.2
1.5	38.1	79	35	32	21	18	16				27.1
1.0	25.4	66	20	18	13	12	11				21.9
0.50	12.7	48	5	5	5	5	5				15.4
0.19	4.75	29									8.7
0.02	0.425	10									3.0
0.003	0.0750	5									1.5
% per category		30	0	0	0	0	20	50	0	0	--> 100%
% Cobble & Sediment		60.0	0.0	0.0	0.0	0.0	40.0	0.0	0.0	0.0	50.0%

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings

U.S. Department of Agriculture, Forest Service, National Technology and Development Program, August 2008.

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

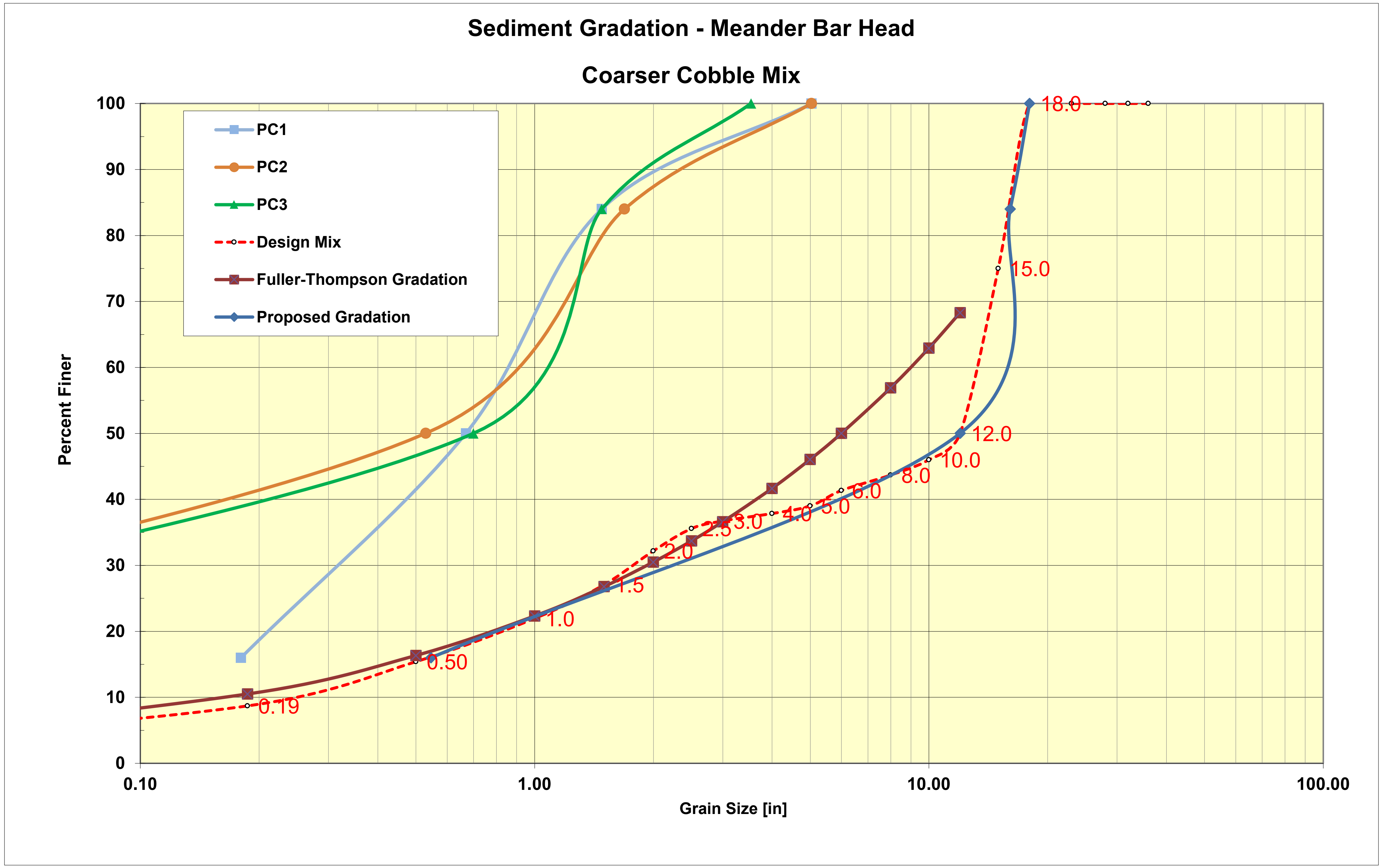
Slopes less than 5%

Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.054	dimensionless Shields parameter for D50, use table E.1 of USFS manual
		or assume 0.045 for poorly sorted channel bed

Flow	2-Year	10-Year	25-Year	50-Year	100-Year	500-Year
Average Modeled Shear Stress (lb/ft^2)	1.10	1.60	1.80	1.90	2.10	2.70
τ_{ci}						
7.70	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
7.44	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
7.14	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
6.73	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
6.26	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
5.92	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
5.54	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
5.25	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
4.91	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
4.50	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
4.26	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
3.98	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
3.66	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
3.46	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
3.24	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.97	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.63	No Motion	No Motion	No Motion	No Motion	No Motion	Motion
2.14	No Motion	No Motion	No Motion	No Motion	No Motion	Motion

D50	12.00	in
	1.00	ft
	304.8	mm

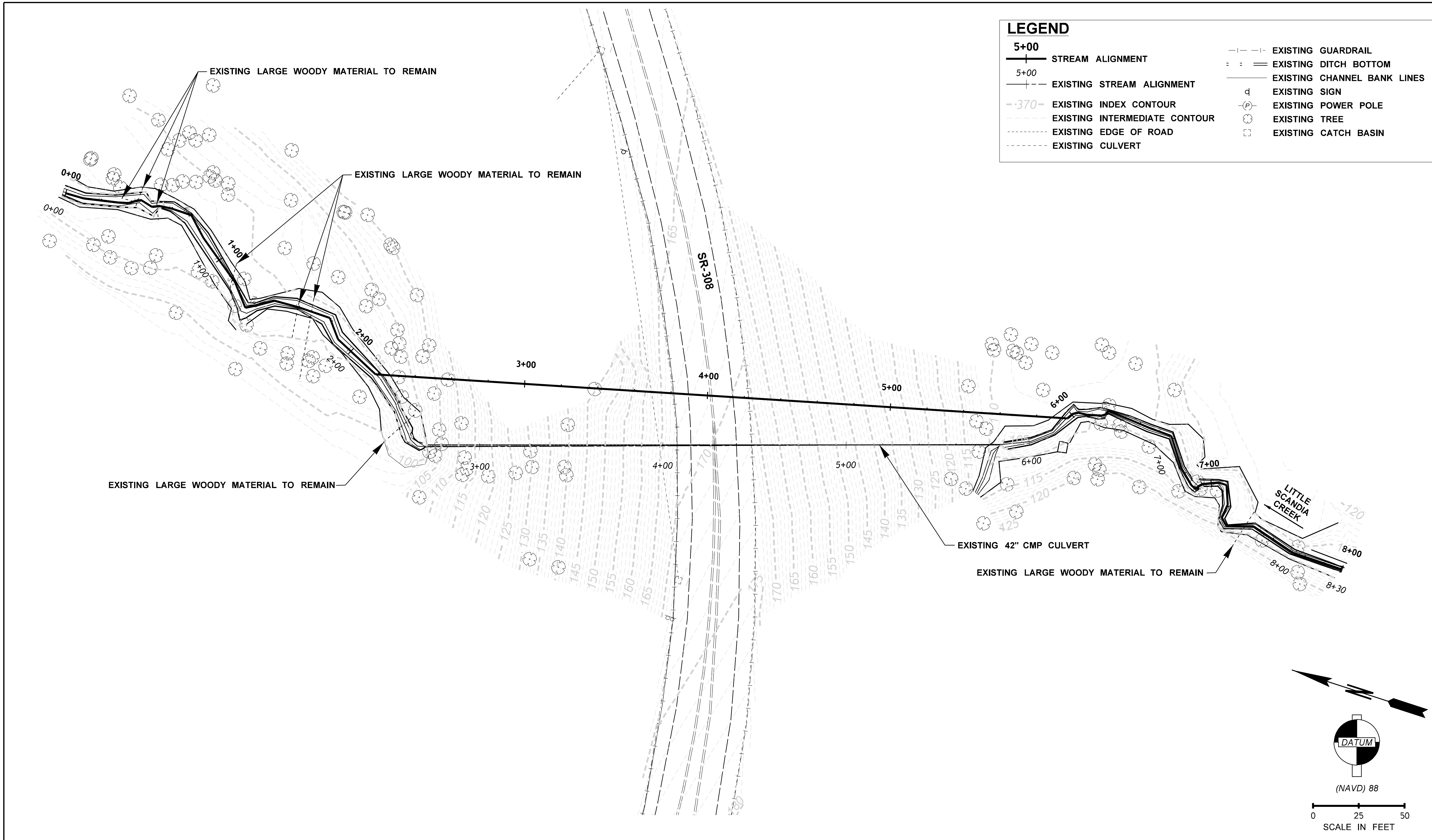


Fuller-Thompson Gradation

Dmax = 28

D[in]	
12.000	68.30
10.000	62.92
8.000	56.91
6.000	50.00
5.000	46.06
4.000	41.66
3.000	36.60
2.500	33.72
2.000	30.50
1.500	26.79
1.000	22.32
0.500	16.34
0.187	10.50
0.017	3.54
0.003	1.62

Appendix D: Stream Plan Sheets, Profile, Details



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DESIGNED BY	M. RICE							
ENTERED BY	C. BENAVIDEZ							
CHECKED BY	-				CONTRACT NO.		LOCATION NO.	
PROJ. ENGR.	-							
REGIONAL ADM.	-	REVISION	DATE	BY				

PRELIMINARY

NOT FOR CONSTRUCTION

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 308 MP 01.33
LITTLE SCANDIA CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

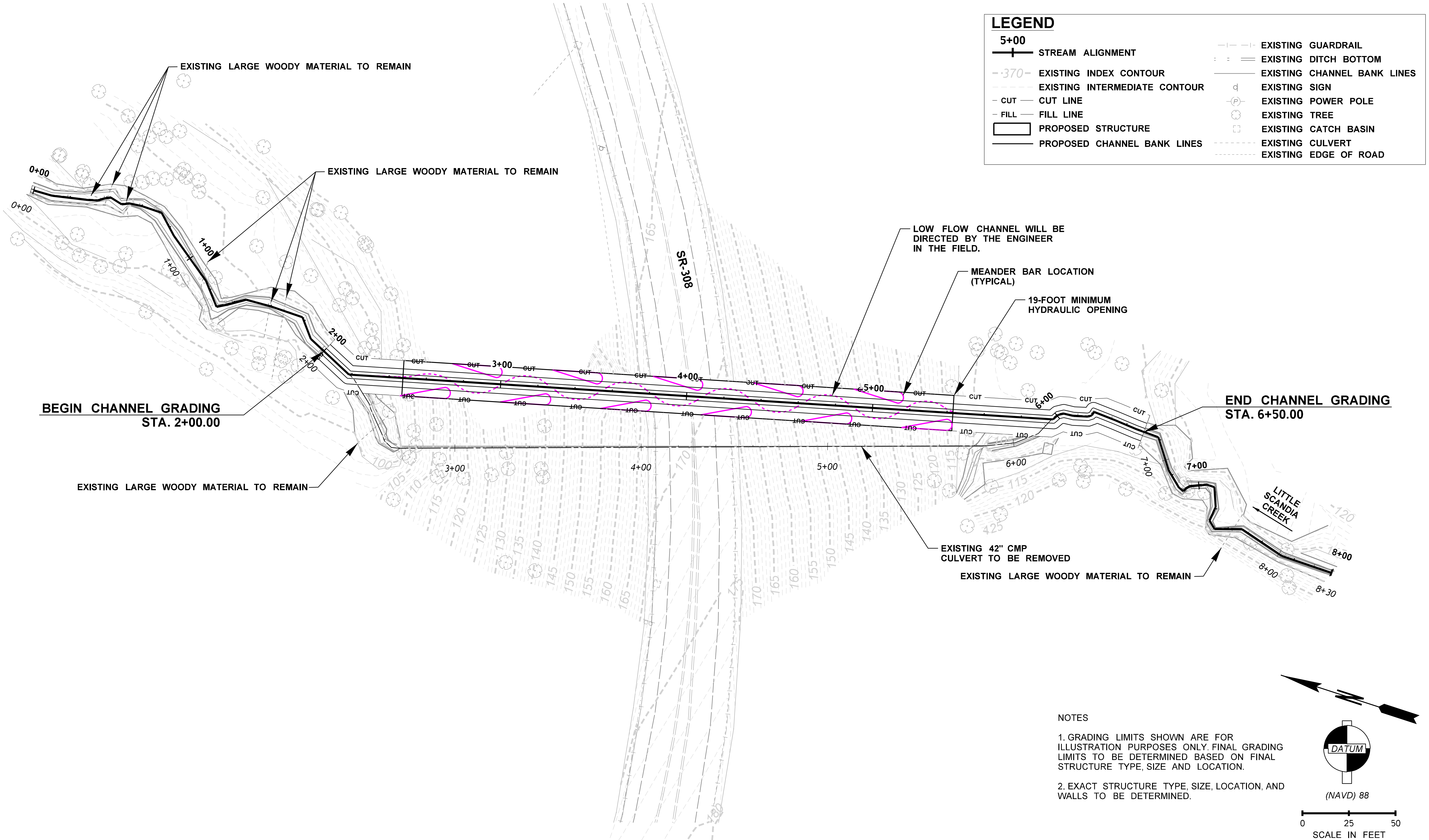
EXISTING STREAM PLAN

PLAN REF NO

SHEET

OF

SHEETS



NOTES

1. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL GRADING LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE TYPE, SIZE AND LOCATION.

2. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED.

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REGIONAL ADM.	-

REVISION | DATE | BY

REGION NO. | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

PRELIMINARY
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DATE P.E. STAMP BOX | DATE P.E. STAMP BOX

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 308 MP 01.33
LITTLE SCANDIA CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

PROPOSED STREAM PLAN

PLAN REF NO

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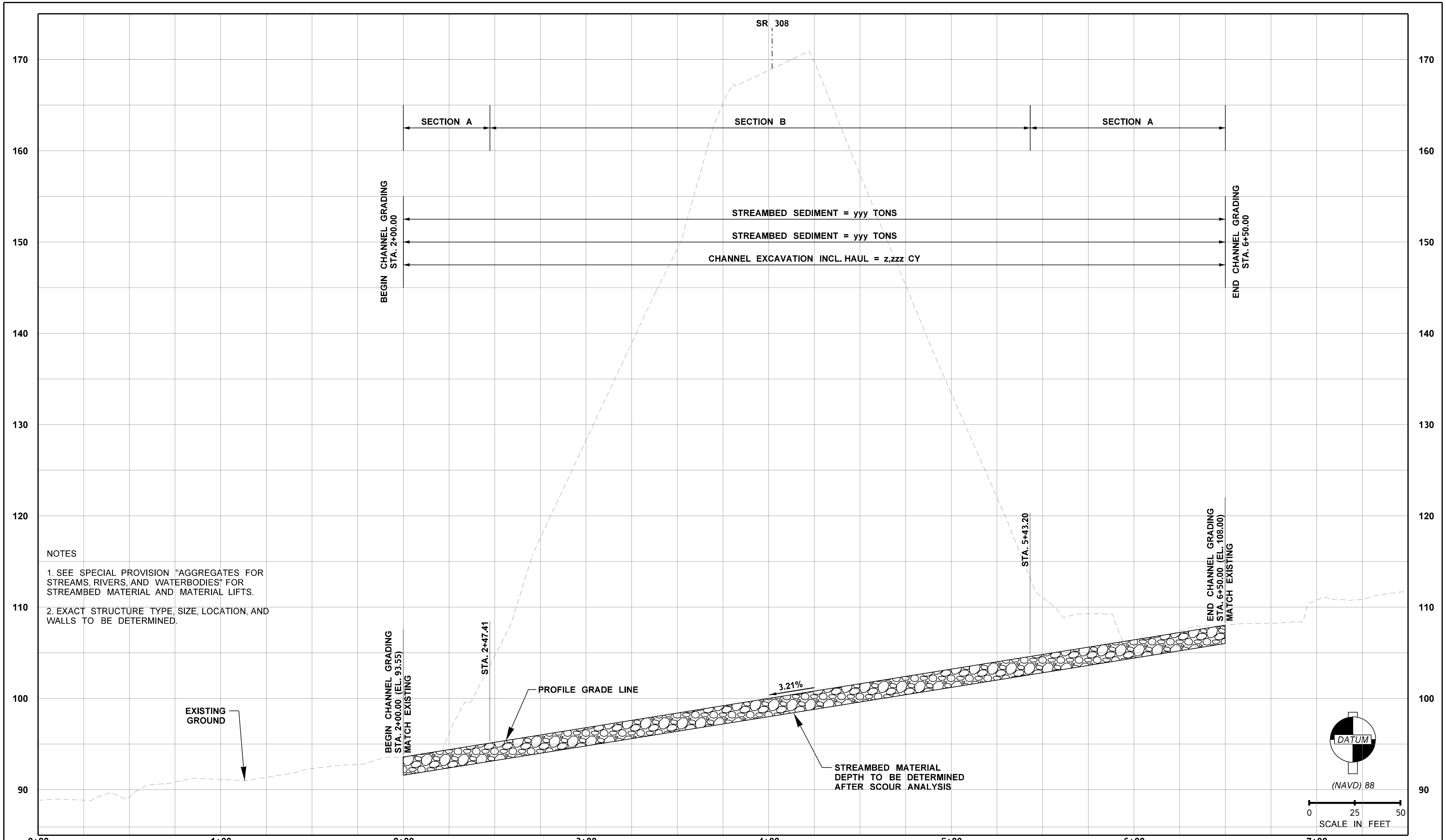

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ENTERED BY C. BENAVIDEZ
CHECKED BY -
PROJ. ENGR. -
REGIONAL ADM. -

REVISION | DATE | BY

REGION NO. | STATE WASH | FED.AID PROJ.NO.
JOB NUMBER
CONTRACT NO. | LOCATION NO.

PRELIMINARY
NOT FOR CONSTRUCTION

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DAVID EVANS AND ASSOCIATES INC.

SR 308 MP 01.33
LITTLE SCANDIA CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

STREAM PROFILE

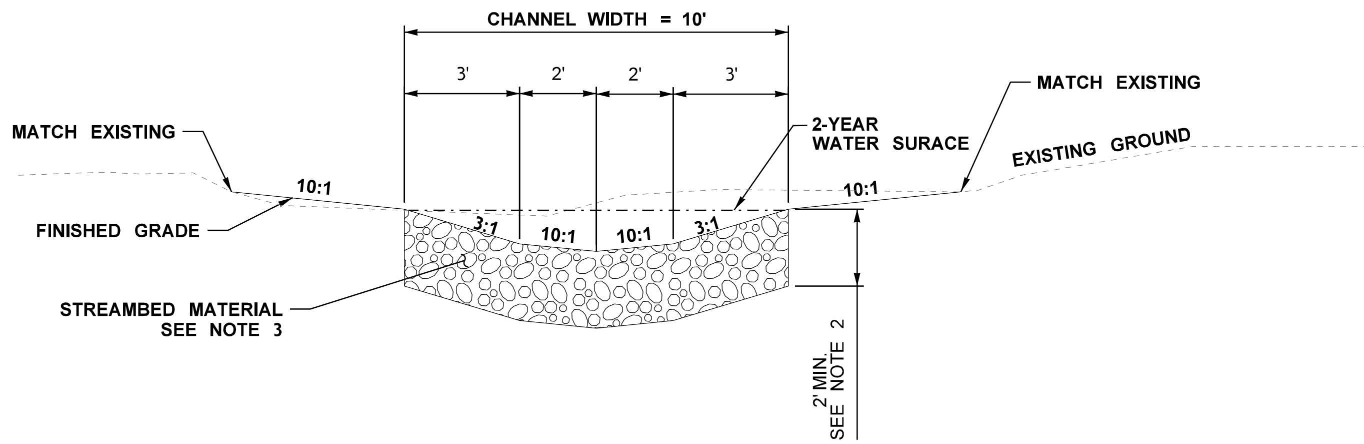
PLAN REF NO
SHEET
OF
SHEETS

STREAM PROFILE

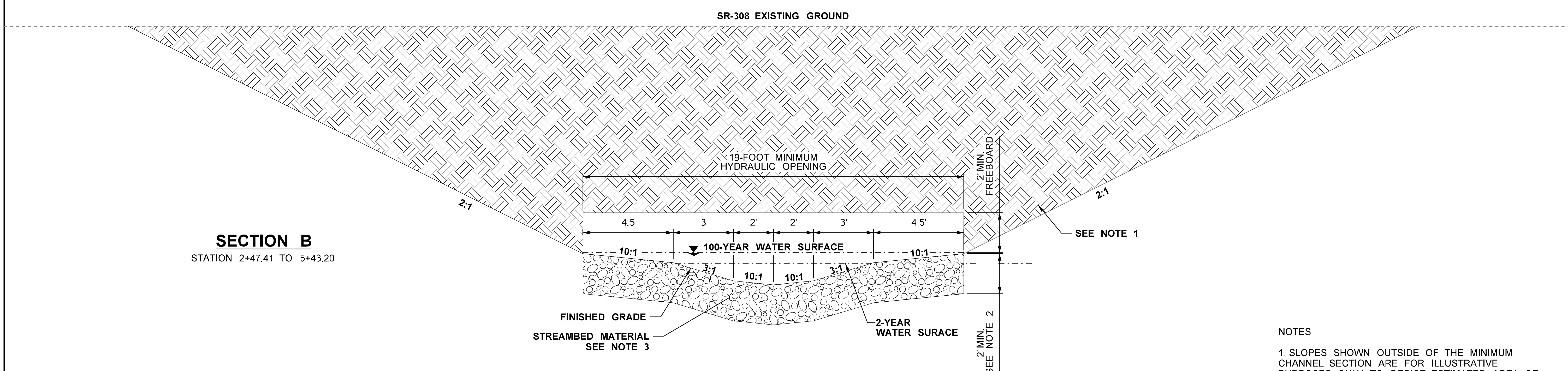
SECTION A

STATION 2+00.00 TO 2+47.41
STATION 5+43.20 TO 6+50.00

FROM STATION 2+00.00 TO 2+20.00 AND FROM STATION 6+30.00 TO 6+50.00, EVENLY TAPER SECTIONS TO MATCH EXISTING CHANNEL.



TYPICAL CHANNEL



SECTION B

STATION 2+47.41 TO 5+43.20

TYPICAL CHANNEL INSIDE STRUCTURE

NOTES

1. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.

2. MATERIAL DEPTH IS APPROXIMATE, FINAL DEPTH TO BE DETERMINED AFTER SCOUR ANALYSIS.

3. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS AND WATERBODIES".

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PRELIMINARY
NOT FOR CONSTRUCTION

DATE P.E. STAMP BOX
DATE P.E. STAMP BOX

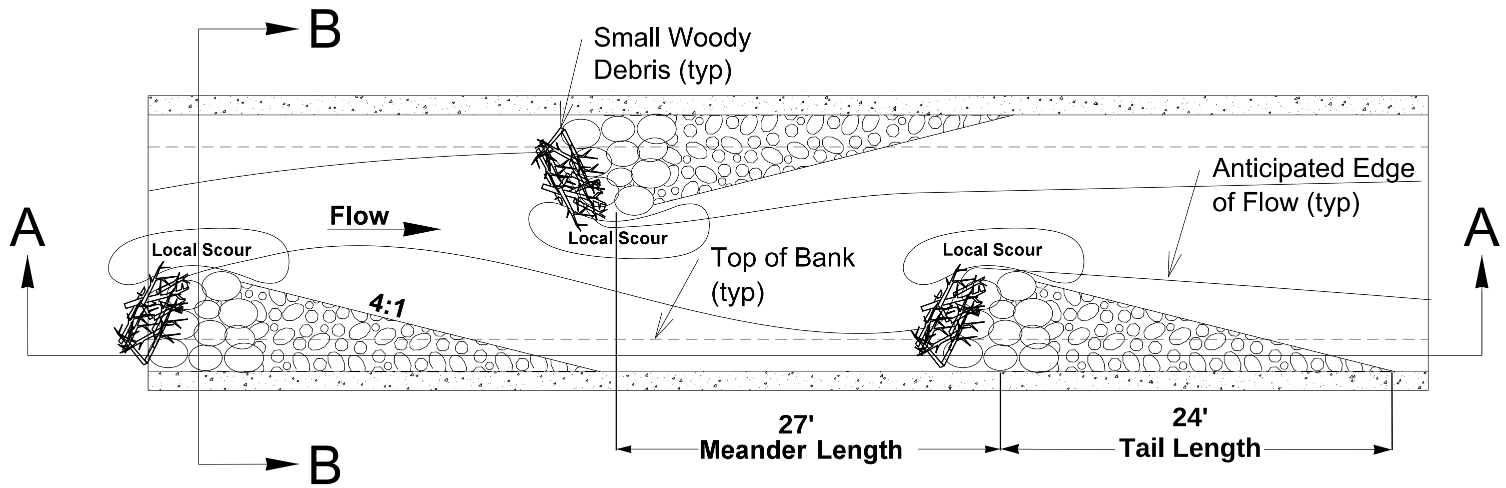
Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 308 MP 01.33
LITTLE SCANDIA CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

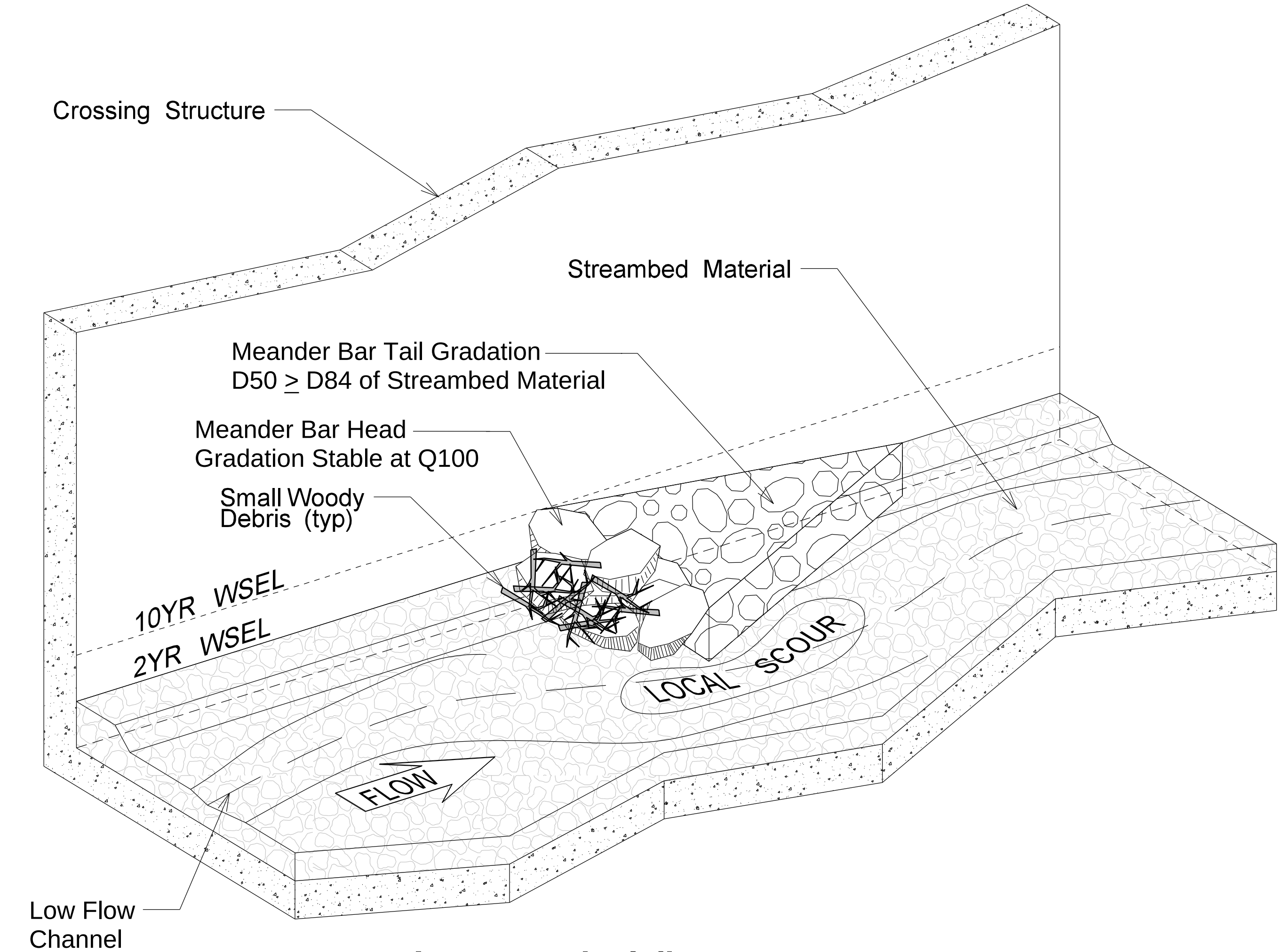
STREAM DETAILS

PLAN REF NO
SHEET
OF
SHEETS



Plan View

NOT TO SCALE



Isometric View

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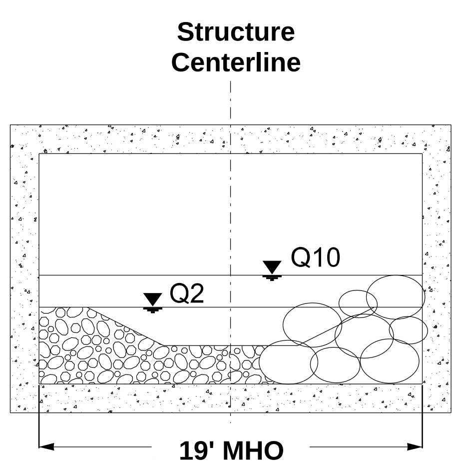

Q2 Depth = 1.1 feet
Q10 Depth = 1.3 feet

Section B-B

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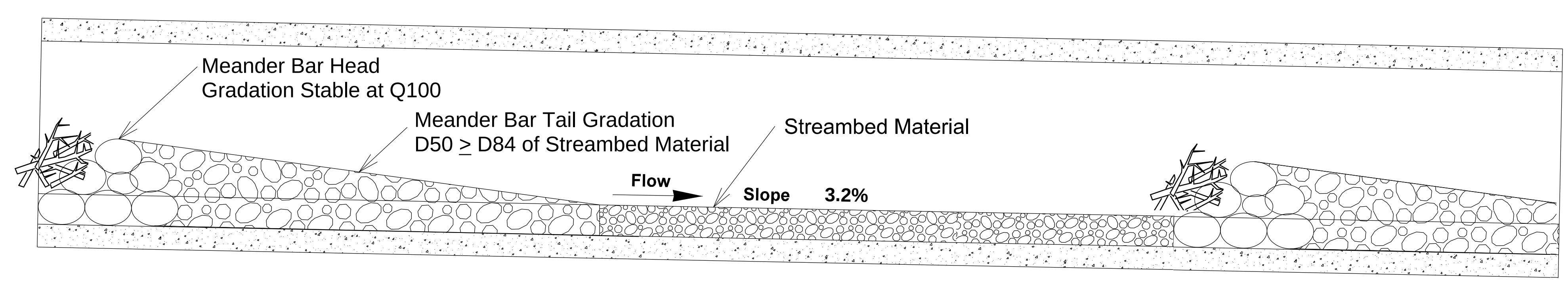

Section A-A

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PROJ. ENGR. -
REGIONAL ADM. -

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
	WASH	
JOB NUMBER		
CONTRACT NO.	LOCATION NO.	

PRELIMINARY

NOT FOR CONSTRUCTION

DATE P.E. STAMP BOX DATE P.E. STAMP BOX

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 308 MP 01.33
LITTLE SCANDIA CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

MEANDER BAR DETAIL

PLAN REF NO

SHEET OF SHEETS

Appendix E: Manning's Calculations

(Not used)

Appendix F: Large Woody Material Calculations

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	*SR 308*	Key piece volume	***1.310***	*yd3*
Stream name	*Little Scandia Creek*	Key piece/ft	***0.0335***	*per ft stream*
length of regrade[a]	*450 ft*	Total wood vol./ft	***0.3948***	*yd3/ft stream*
Bankfull width	*10 ft*	Total LWM[c] pieces/ft stream	***0.1159***	*per ft stream*
Habitat zone[b]	*Western WA*			

Taper coeff.
LF_{rw}
H_{dbh}

Log type	Diameter at midpoint (ft)	Length(ft)[d]	Volume (yd^3/log)[d]	Rootwad?	Qualifies as key piece?	No. LWM pieces	Total wood volume (yd^3)	DBH based on mid point diameter (ft)	$D_{root\ collar}$ (ft)
A	2.00	*30*	3.49	**yes**	yes	7	24.43	2.12	2.19
B	1.50	*24*	1.57	**yes**	yes	8	12.57	1.58	1.65
C	1.50	*10*	0.65	**yes**	no	9	5.89	1.47	1.54
D	1	*10*	0.29	**no**	no	9	2.62	1.08	1.05
E	0.5	*10*	0.07	**no**	no	19	1.38	0.58	0.57
F			0.00				0.00		0.00
G			0.00				0.00		0.00
H			0.00				0.00		0.00
I			0.00				0.00		0.00
J			0.00				0.00		0.00
K			0.00				0.00		0.00
L			0.00				0.00		0.00
M			0.00				0.00		0.00
N			0.00				0.00		0.00
O			0.00				0.00		0.00
P			0.00				0.00		0.00

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	15	52	46.9
Targets	**15**	**52**	**177.7**
	on target	on target	deficit

[a] includes length through crossing, regardless of structure type

[b] choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information

Western Washington lowl:	(generally <4,200 ft. in elevation west of the Cascade Crest)
Alpine	(generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)
Douglas fir-Ponderosa pine	(mainly east slope Cascades below 3,700 ft. elevation)

[c]LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).

[d]includes rootwad if present

Appendix G: Future Projections for Climate-Adapted Culvert Design

Future Projections for Climate-Adapted Culvert Design

Project Name:

Stream Name:

Drainage Area: 325 ac

Projected mean percent change in bankfull flow:

2040s: 13.2%

2080s: 17.4%

Projected mean percent change in bankfull width:

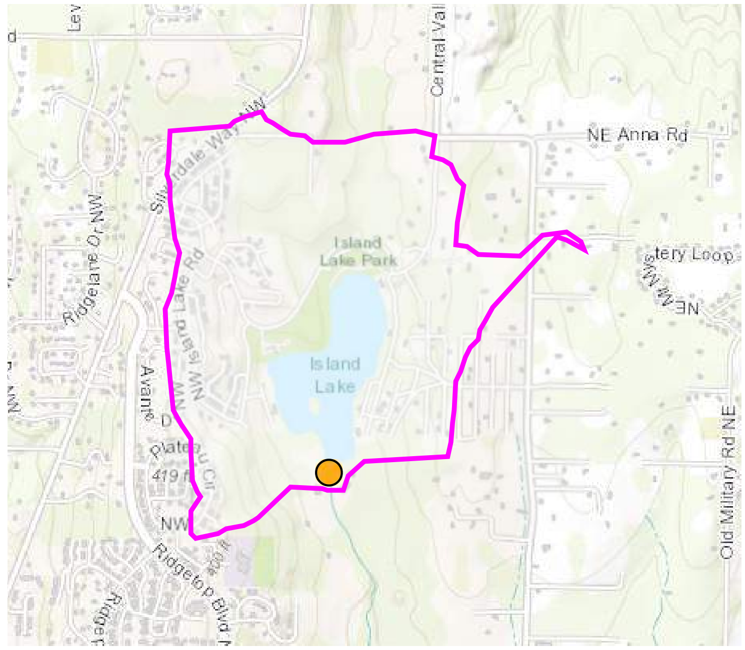
2040s: 6.4%

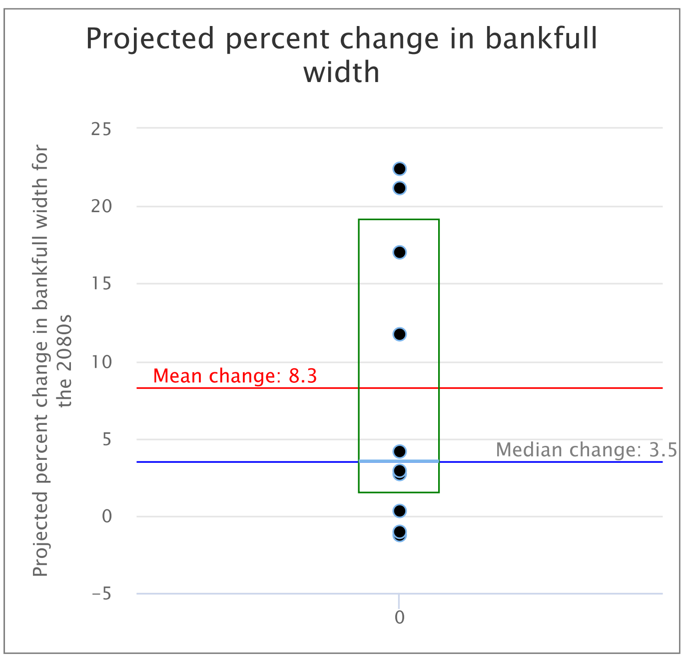
2080s: 8.3%

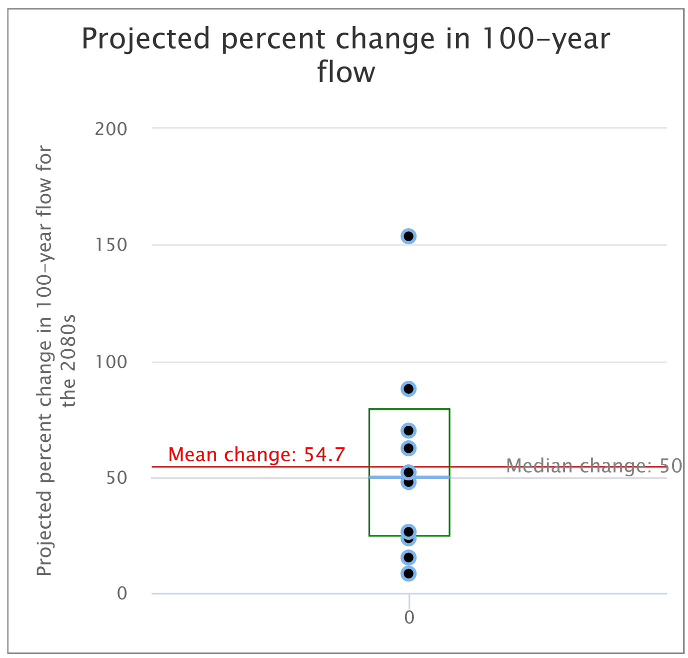
Projected mean percent change in 100-year flood:

2040s: 40.2%

2080s: 54.7%

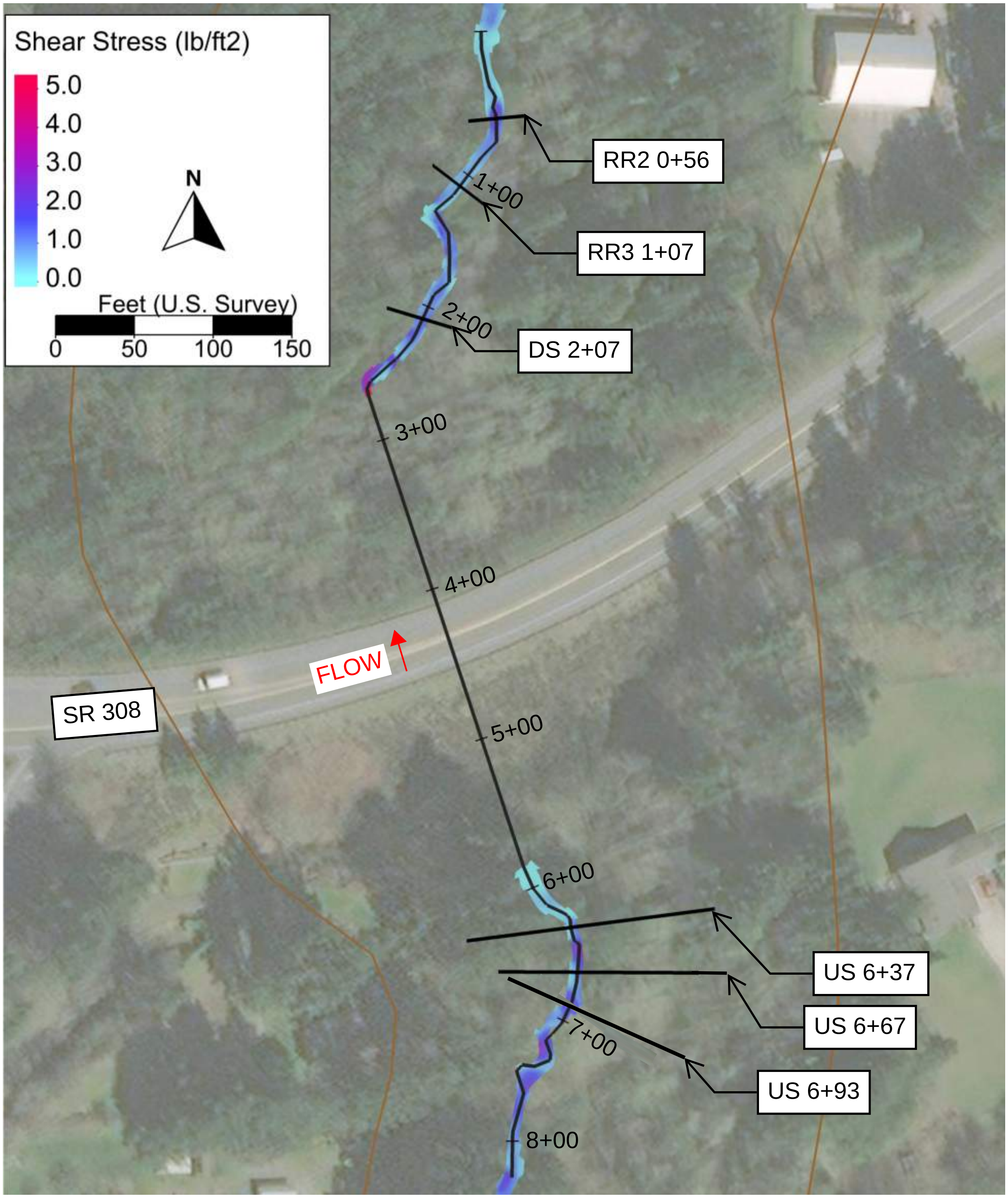




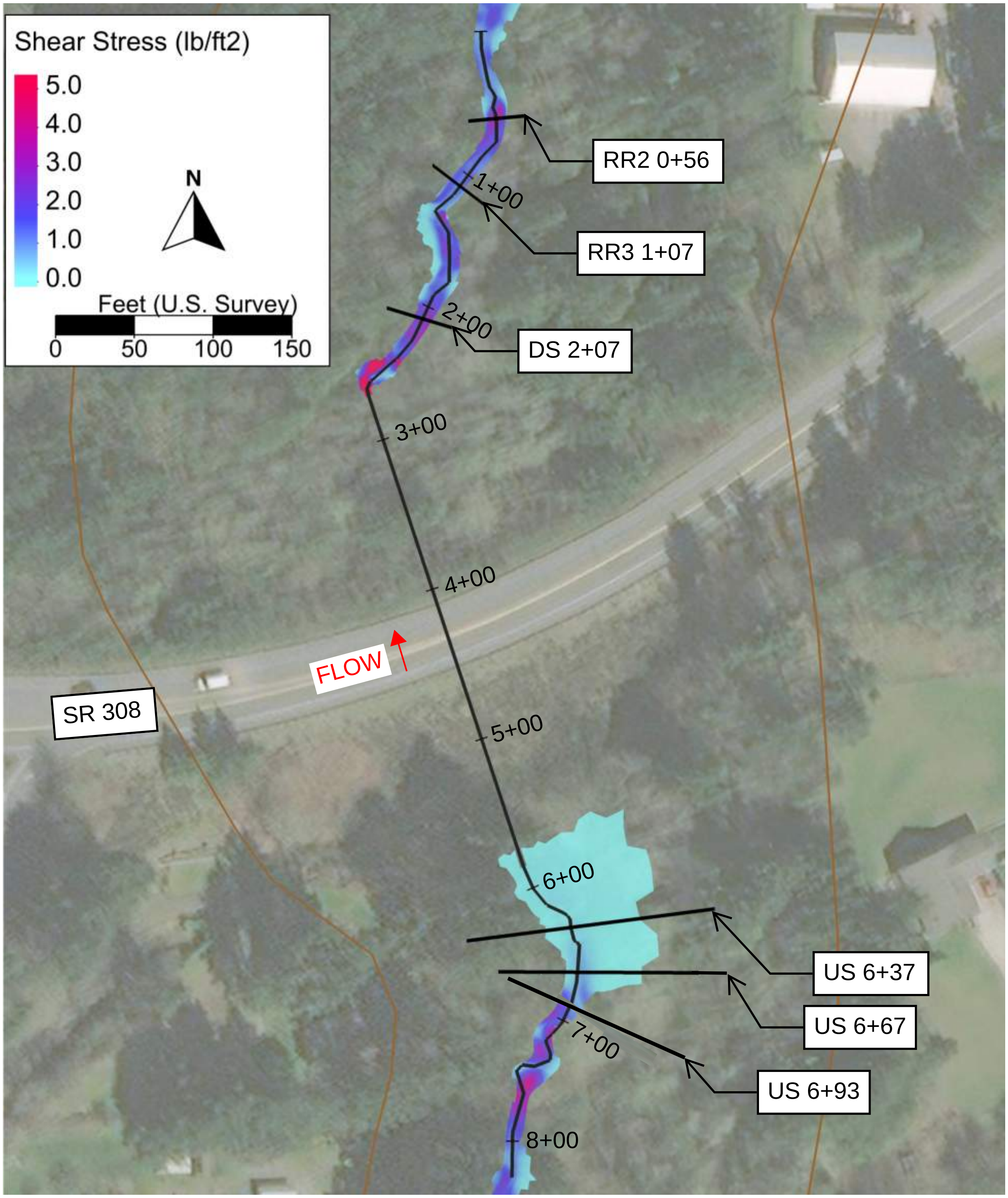


Black dots are projections from 10 separate models

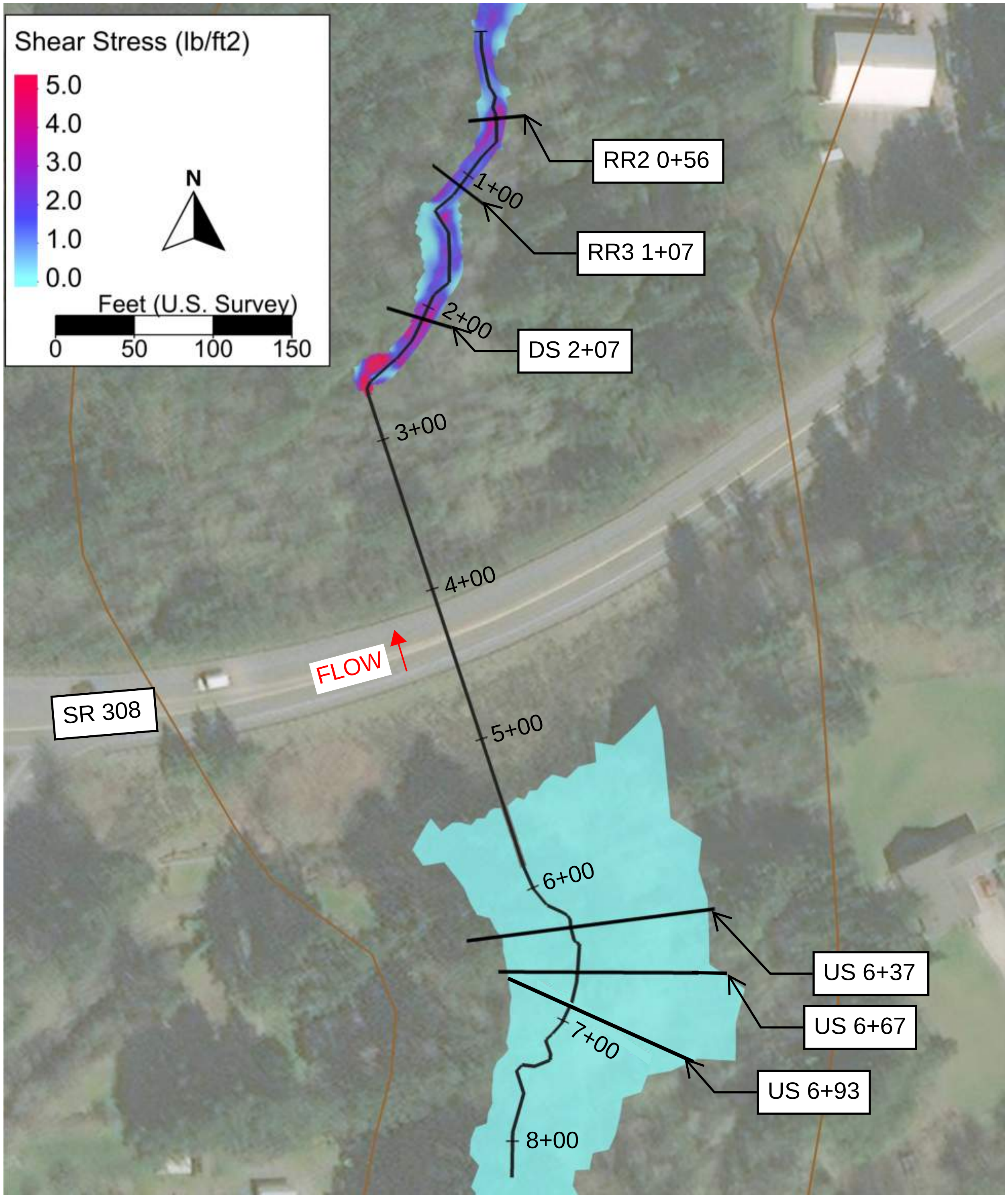
Appendix H: SRH-2D Model Results



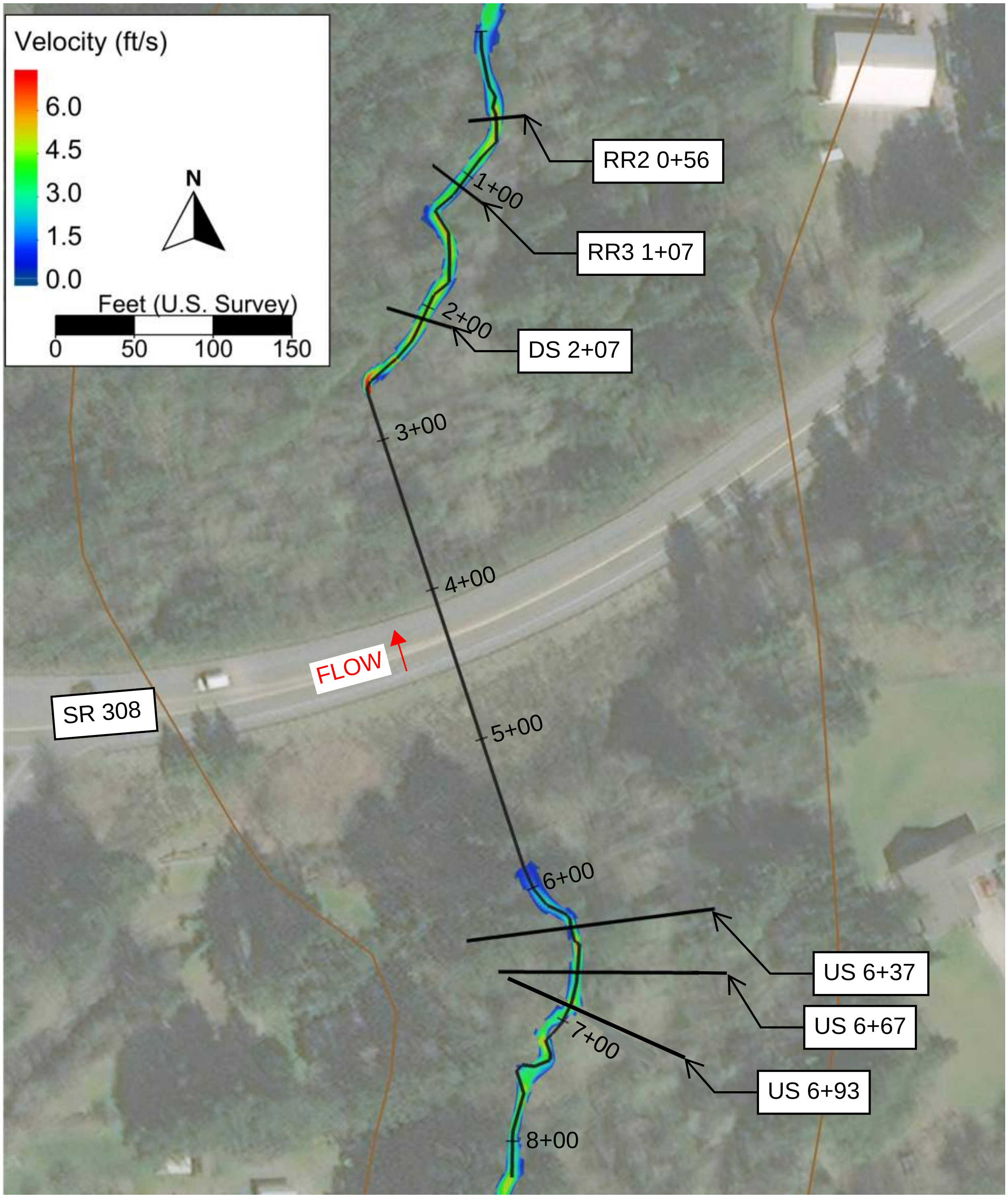
Appendix H.1 - Existing Conditions 2-year Shear Stress



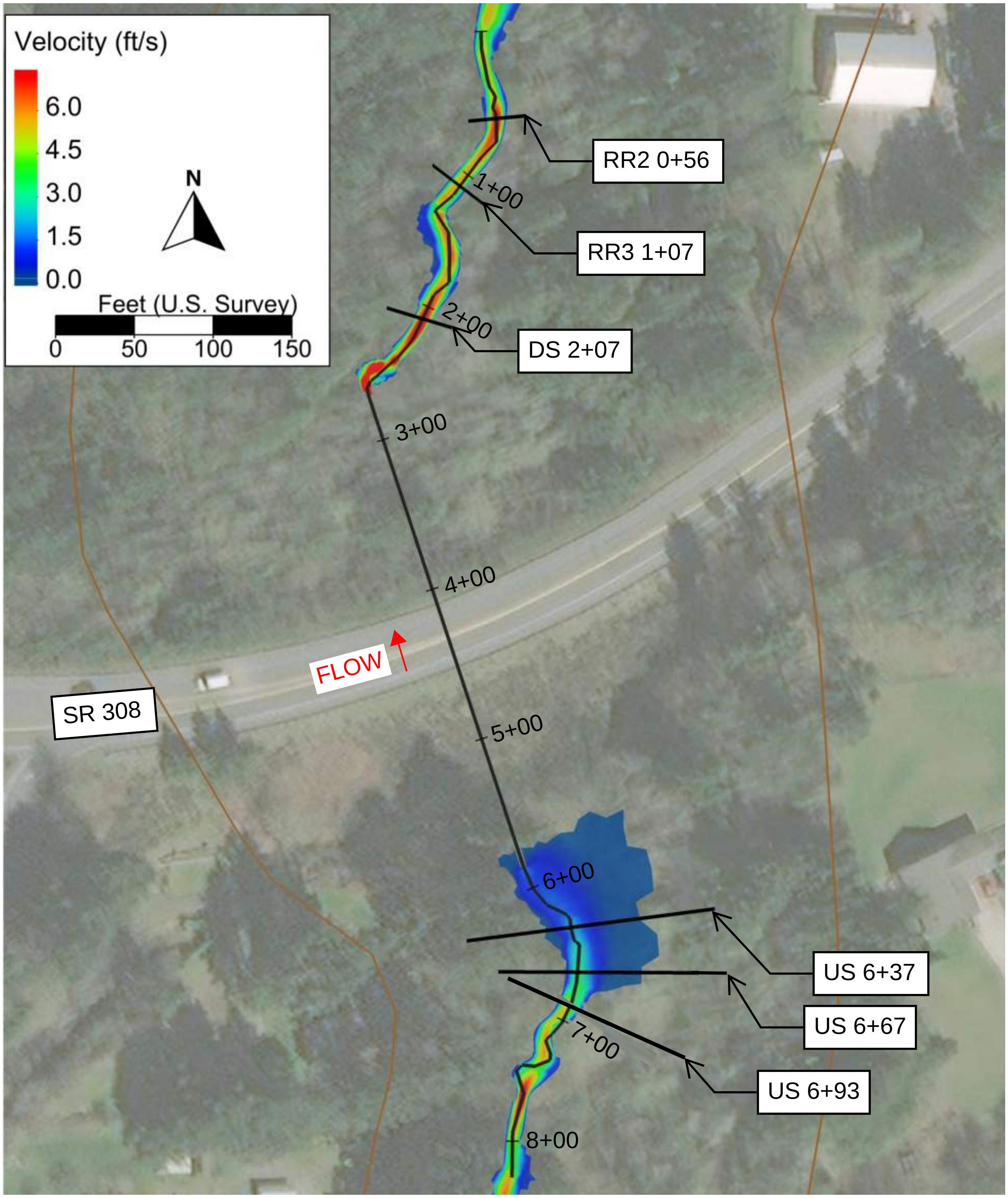
Appendix H.2 - Existing Conditions 100-year Shear Stress



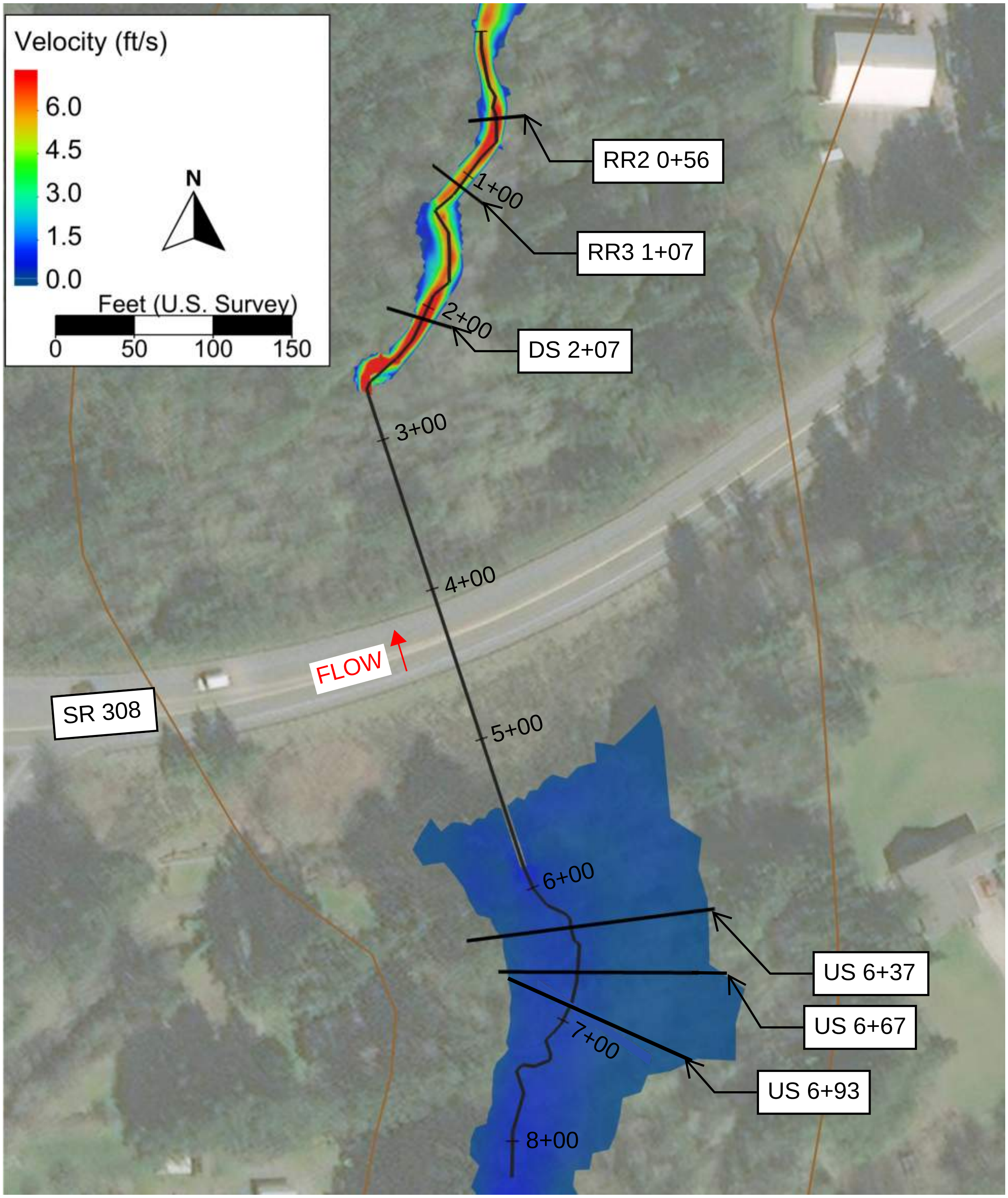
Appendix H.3 - Existing Conditions 500-year Shear Stress



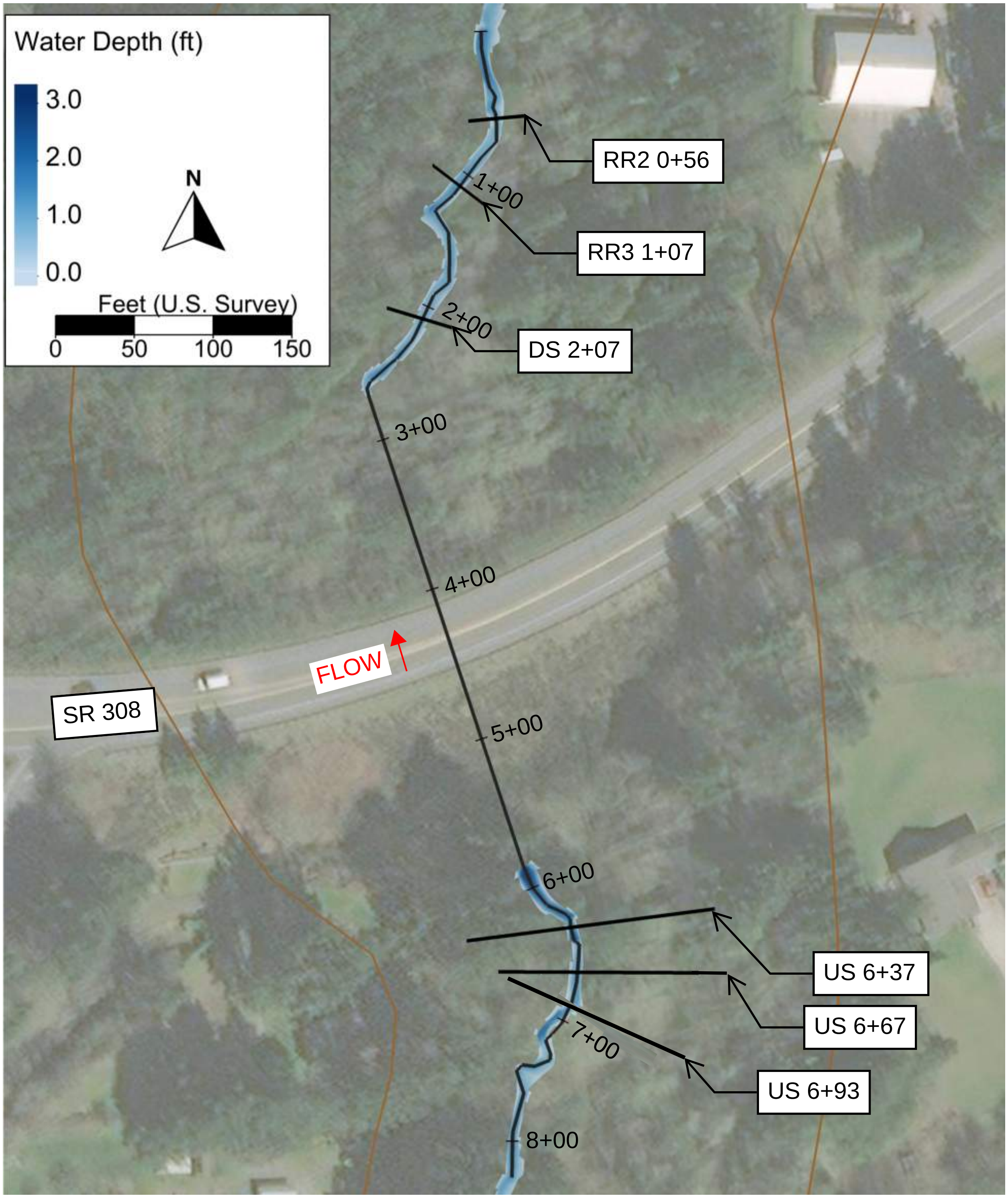
Appendix H.4 - Existing Conditions 2-year Velocity



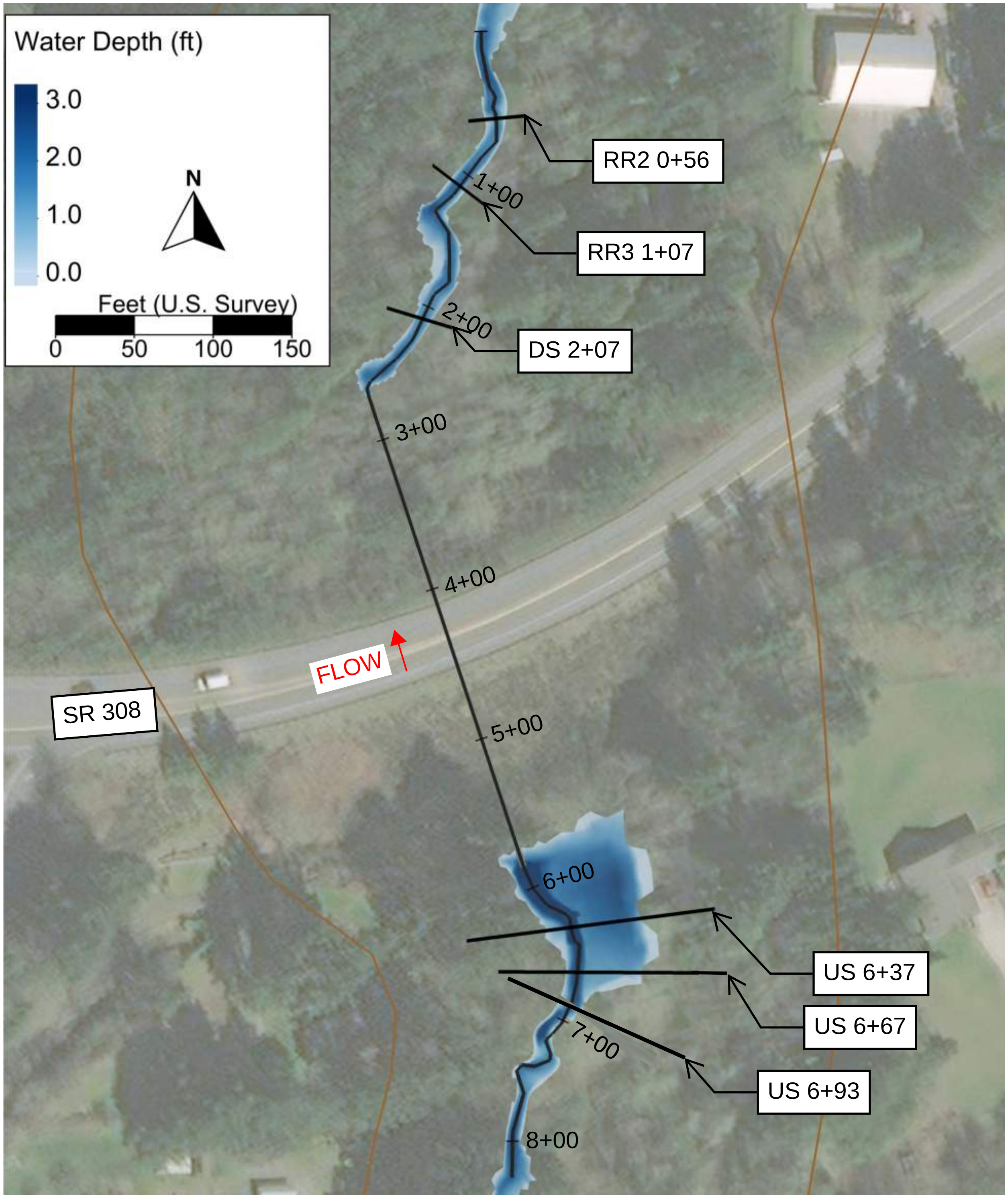
Appendix H.5 - Existing Conditions 100-year Velocity



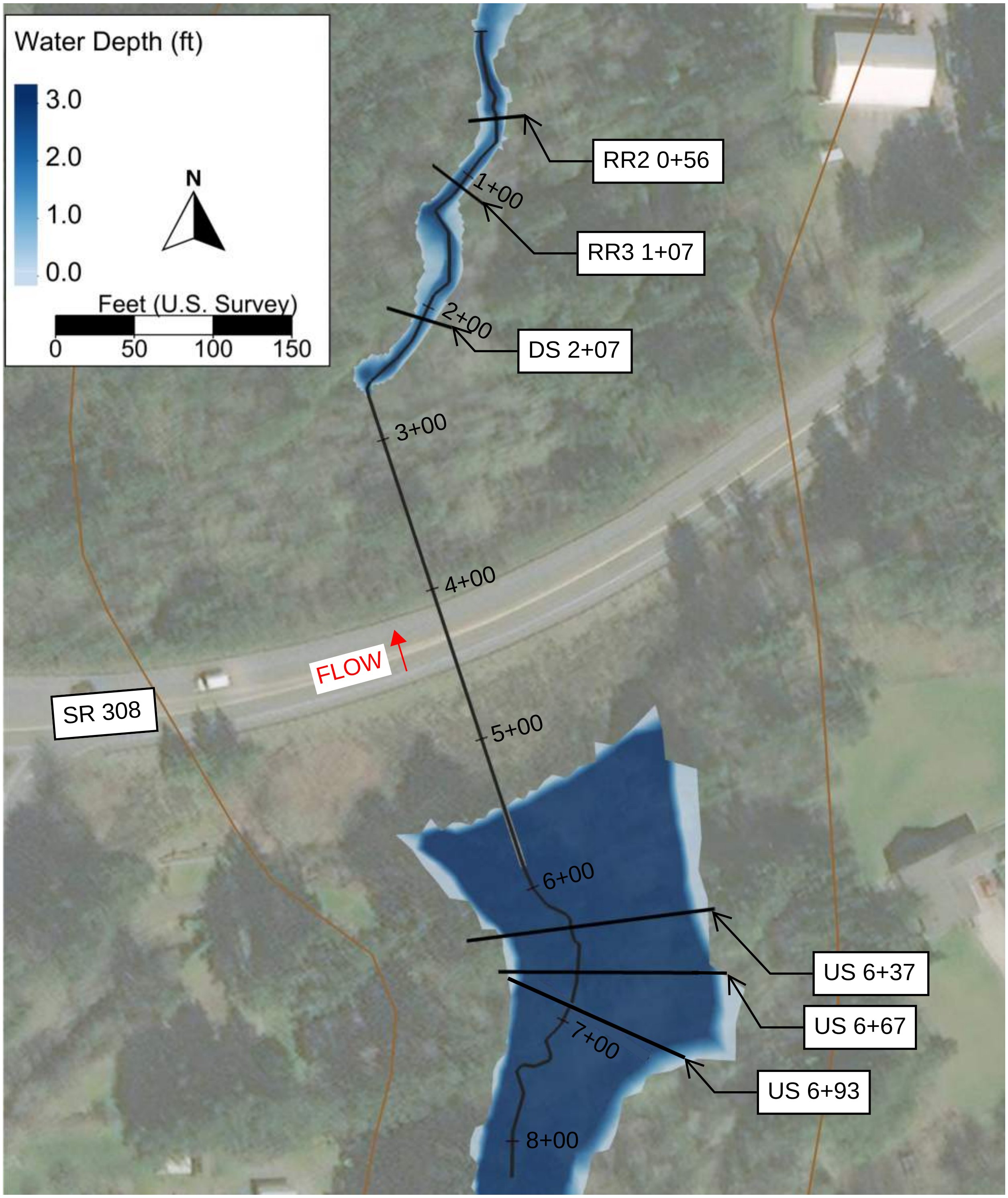
Appendix H.6 - Existing Conditions 500-year Velocity



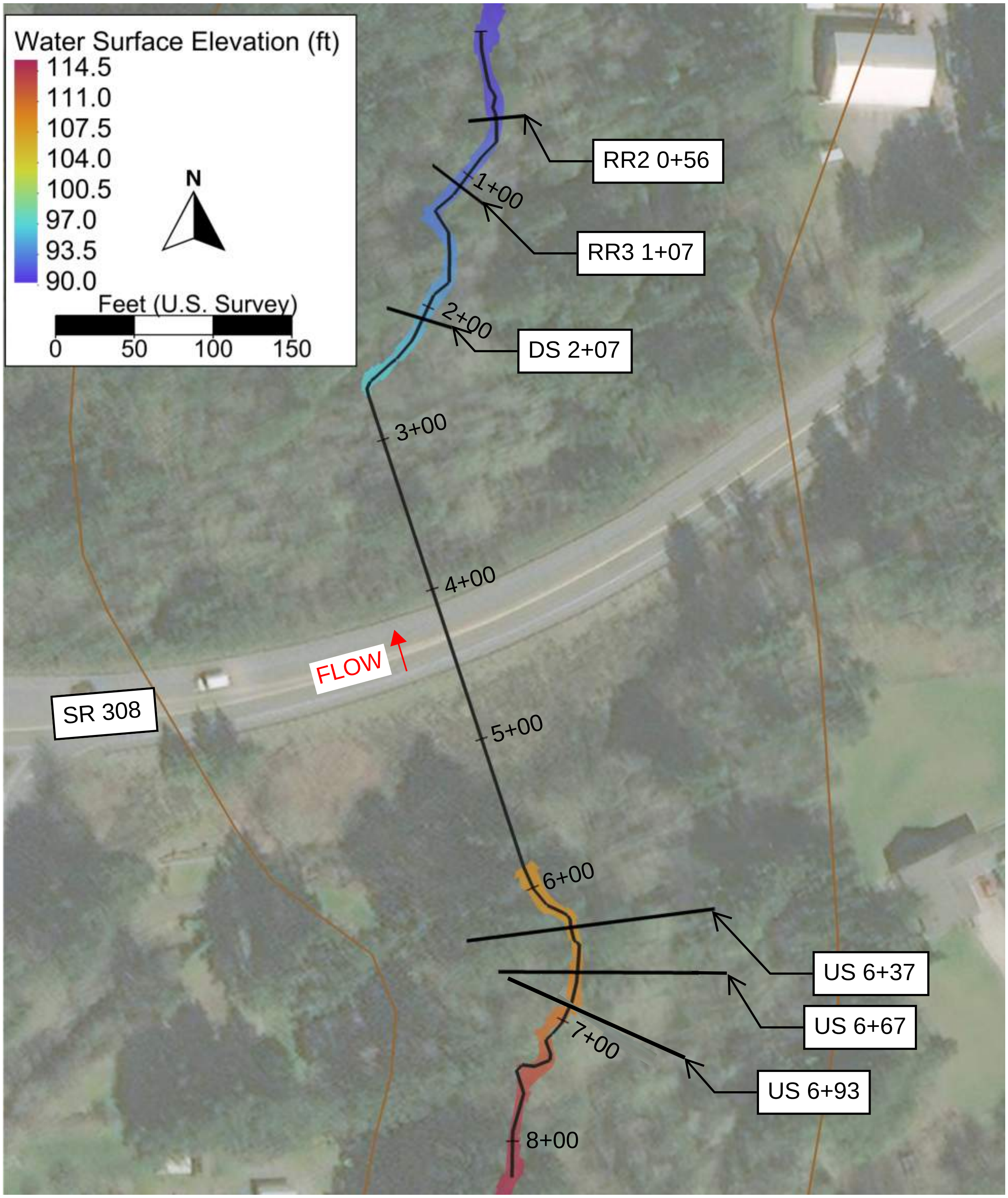
Appendix H.7 - Existing Conditions 2-year Depth



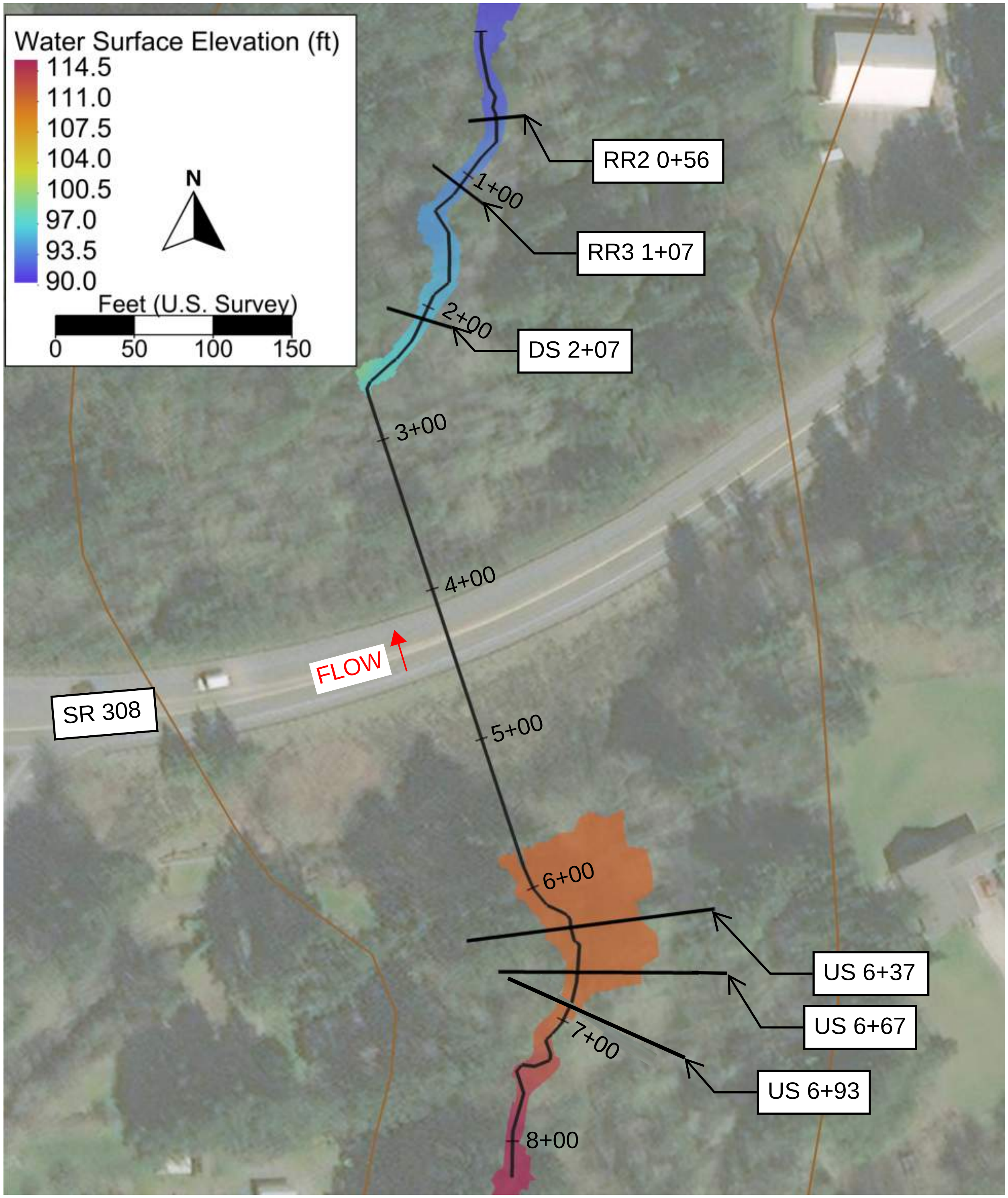
Appendix H.8 - Existing Conditions 100-year Depth



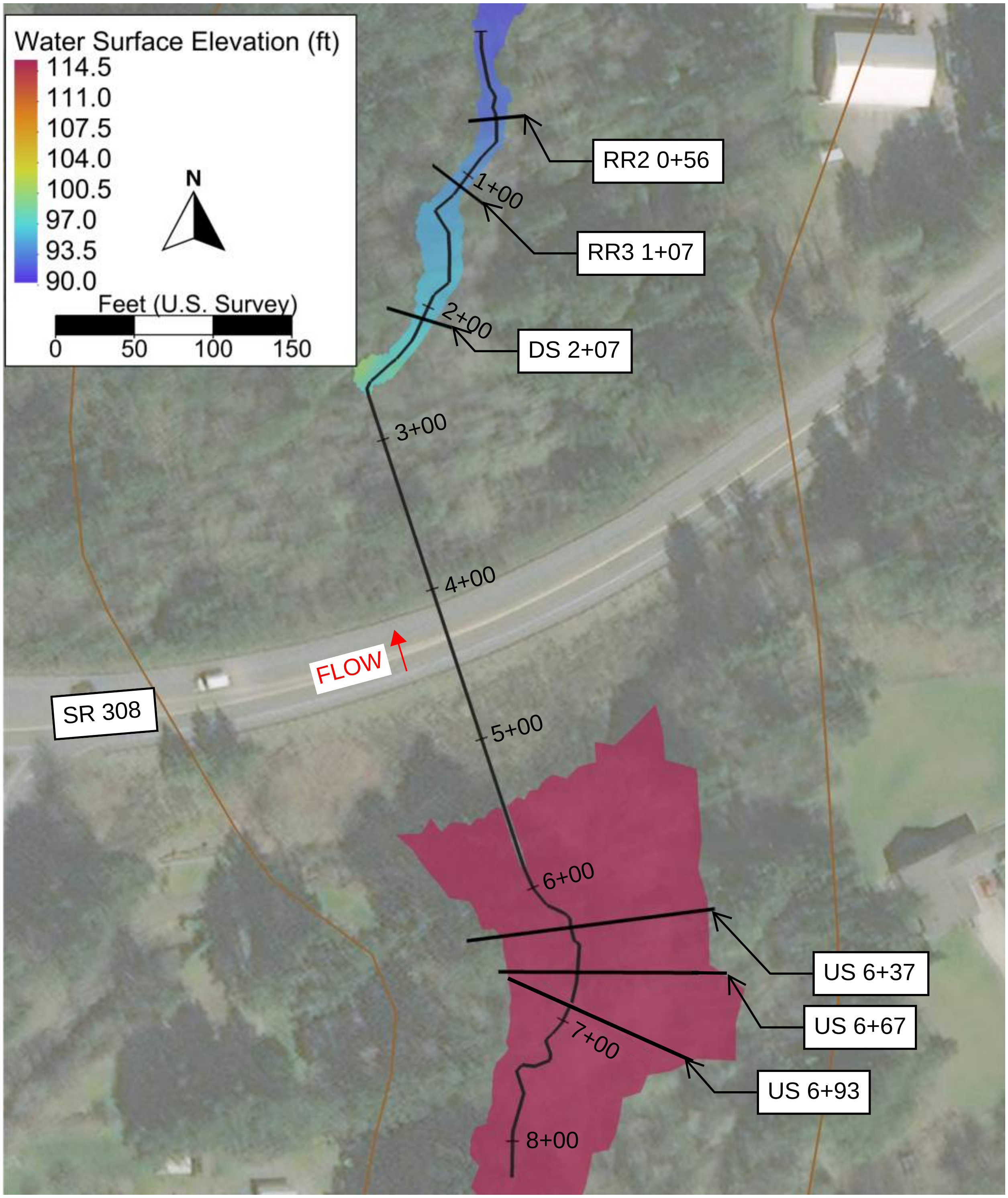
Appendix H.9 - Existing Conditions 500-year Depth



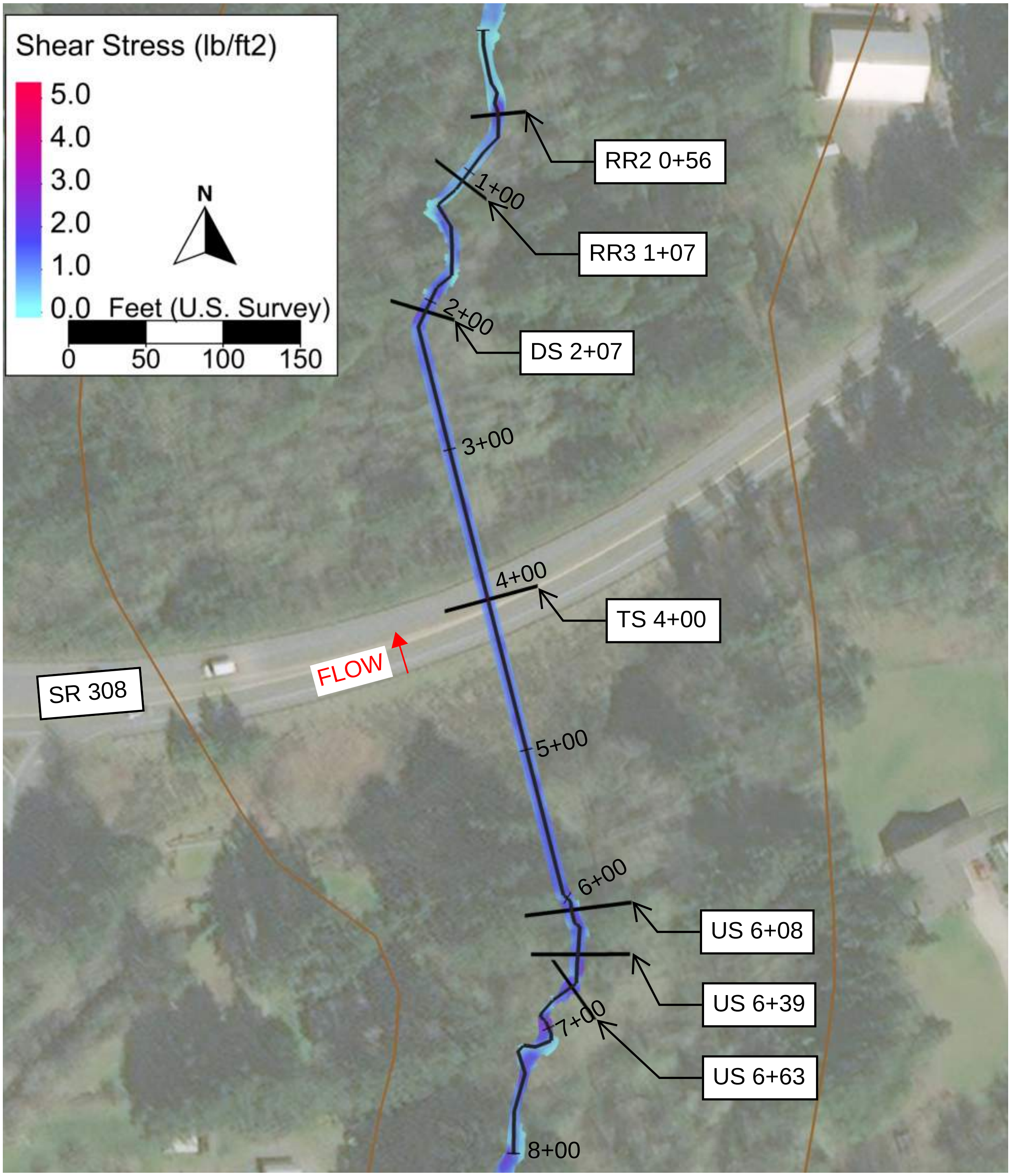
Appendix H.10 - Existing Conditions 2-year Water Surface Elevation



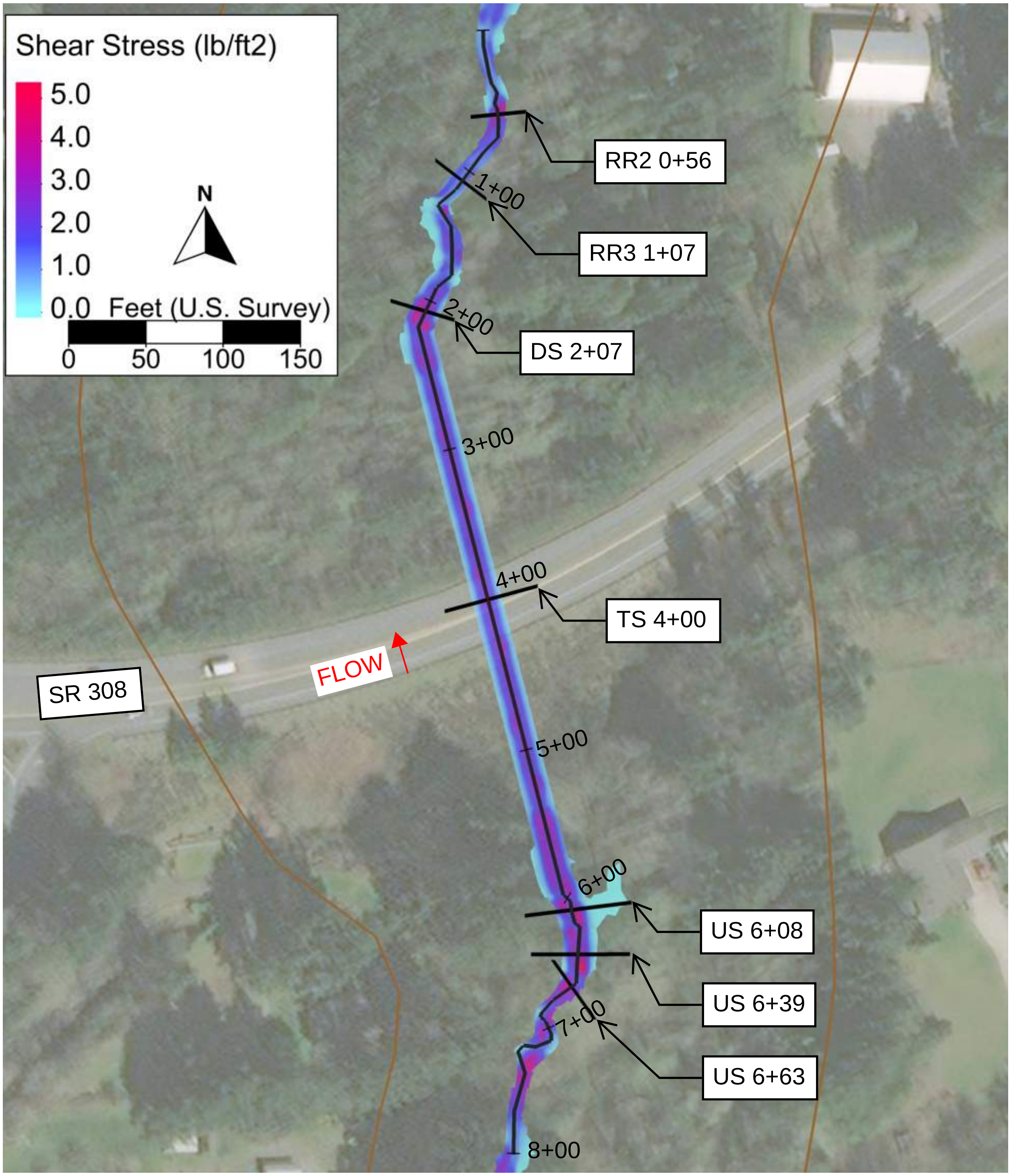
Appendix H.11 - Existing Conditions 100-year Water Surface Elevation



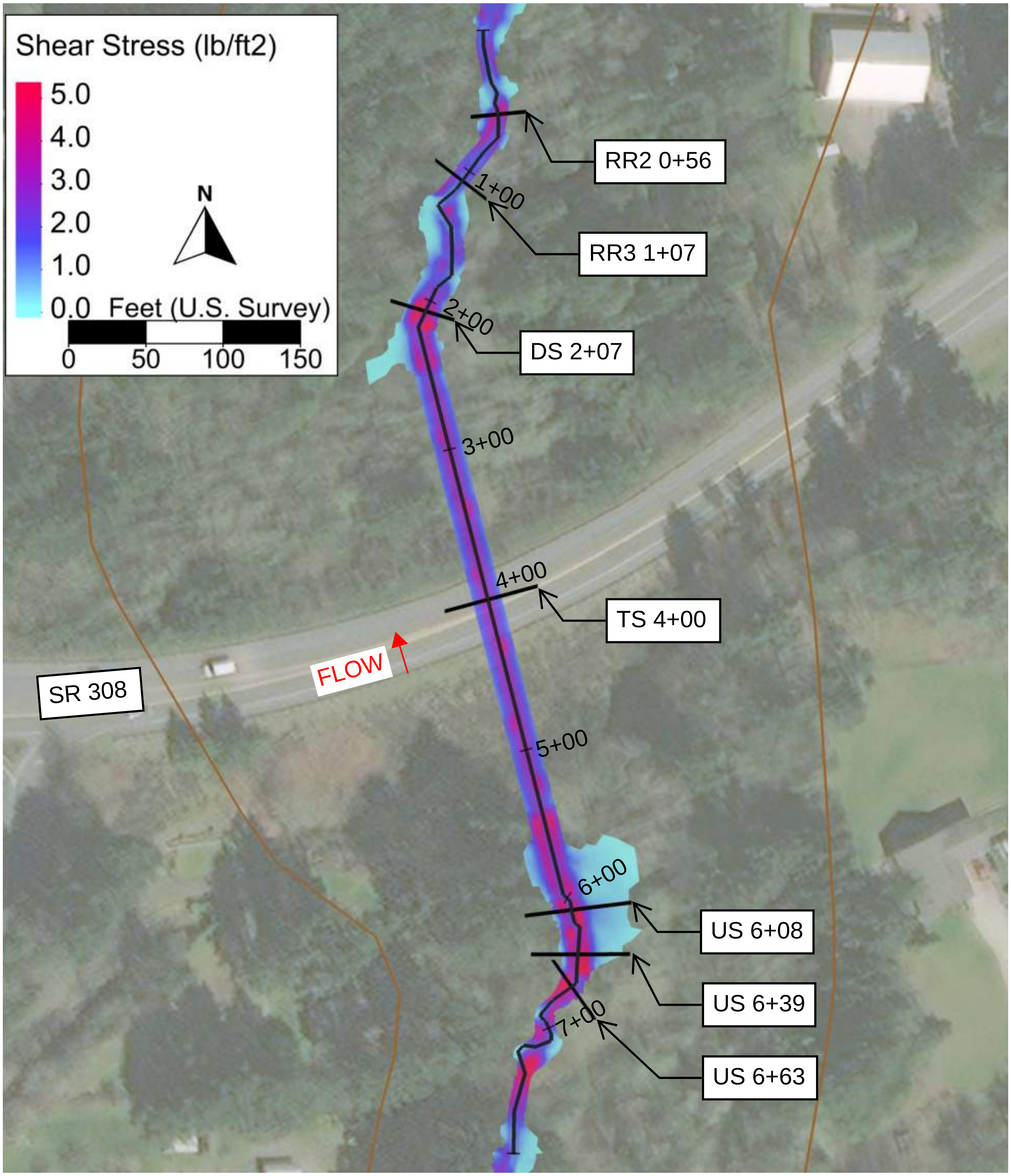
Appendix H.12 - Existing Conditions 500-year Water Surface Elevation



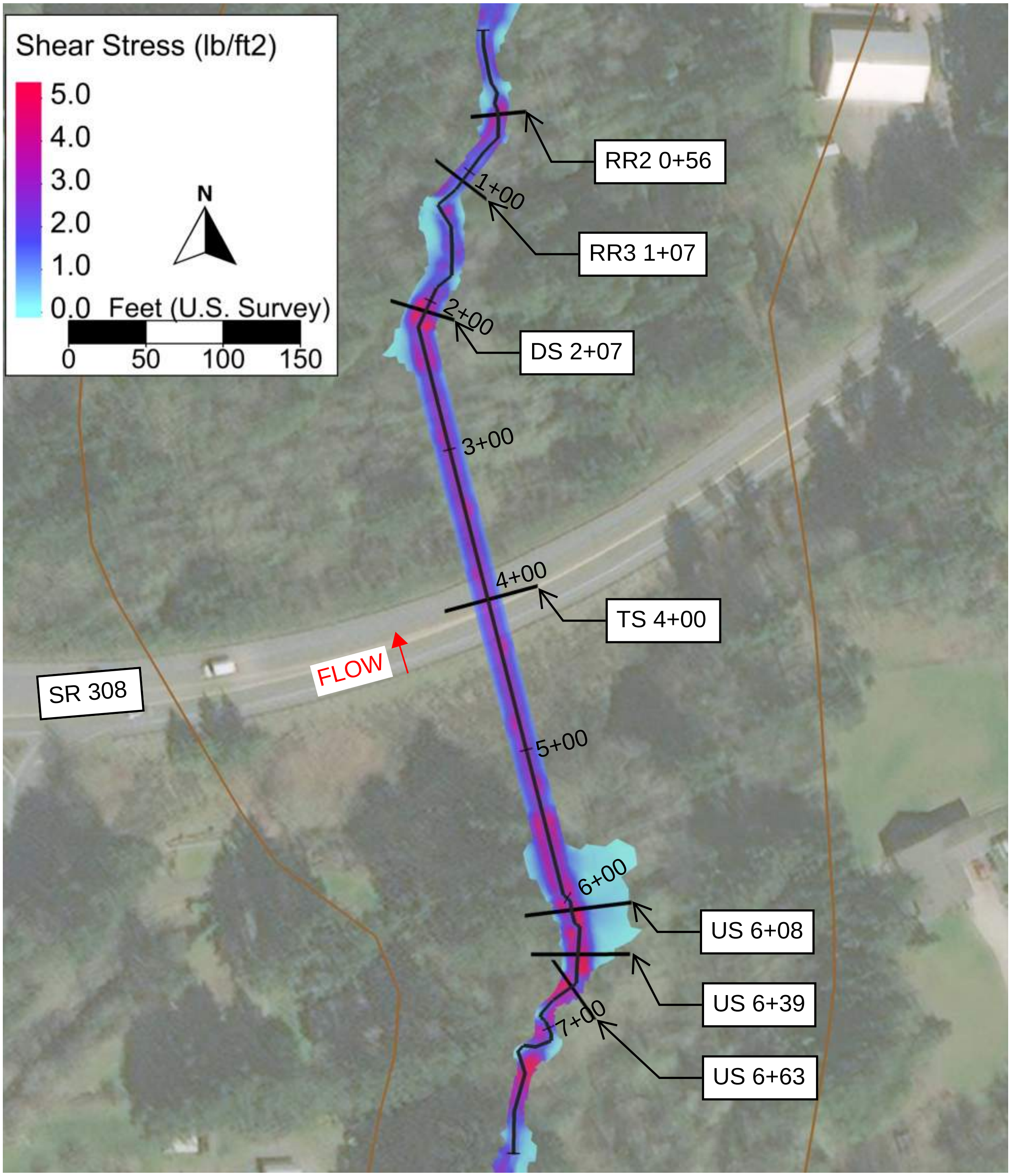
Appendix H.13 - Proposed Conditions 2-year Shear Stress



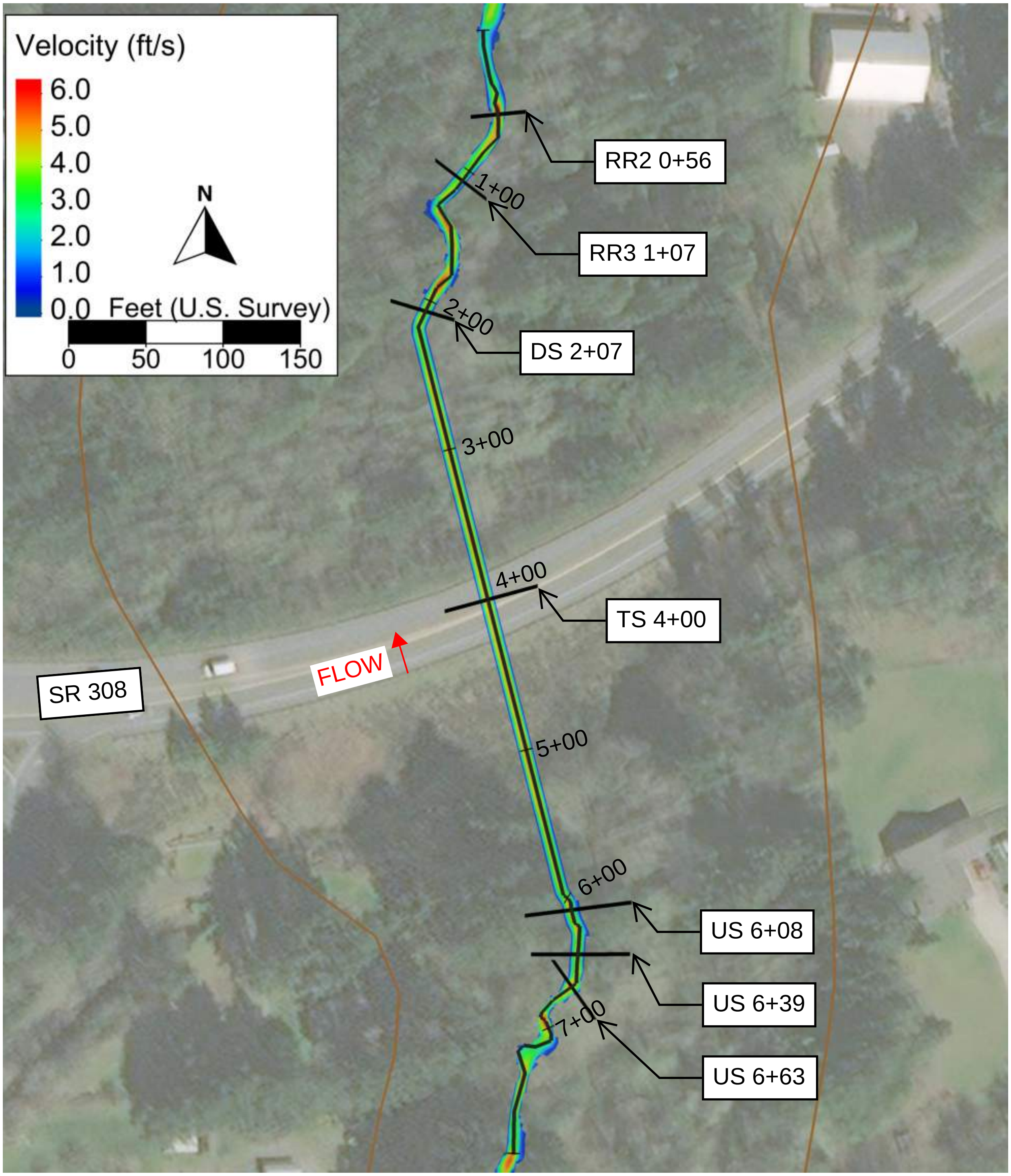
Appendix H.14 - Proposed Conditions 100-year Shear Stress



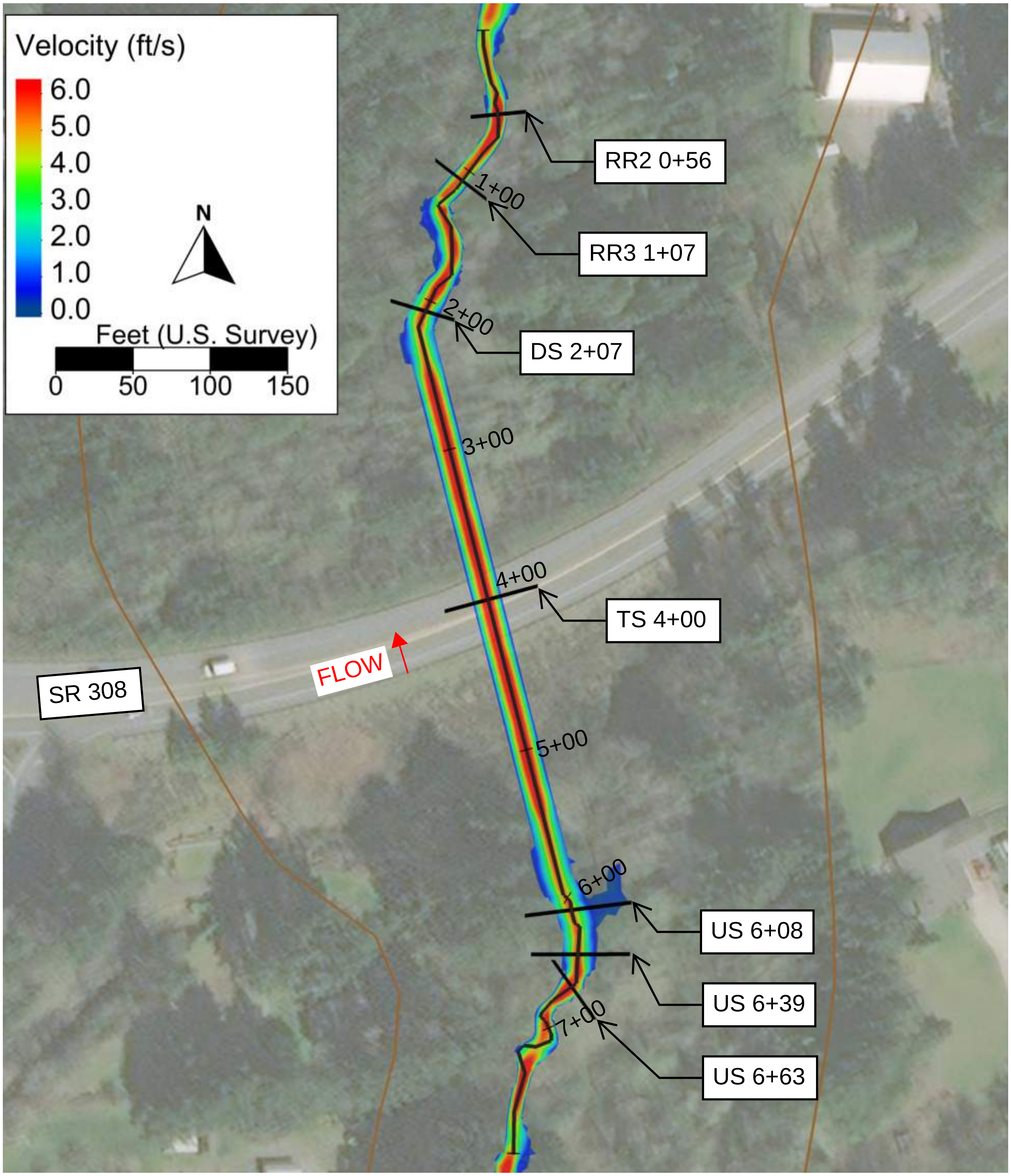
Appendix H.15 - Proposed Conditions 500-year Shear Stress



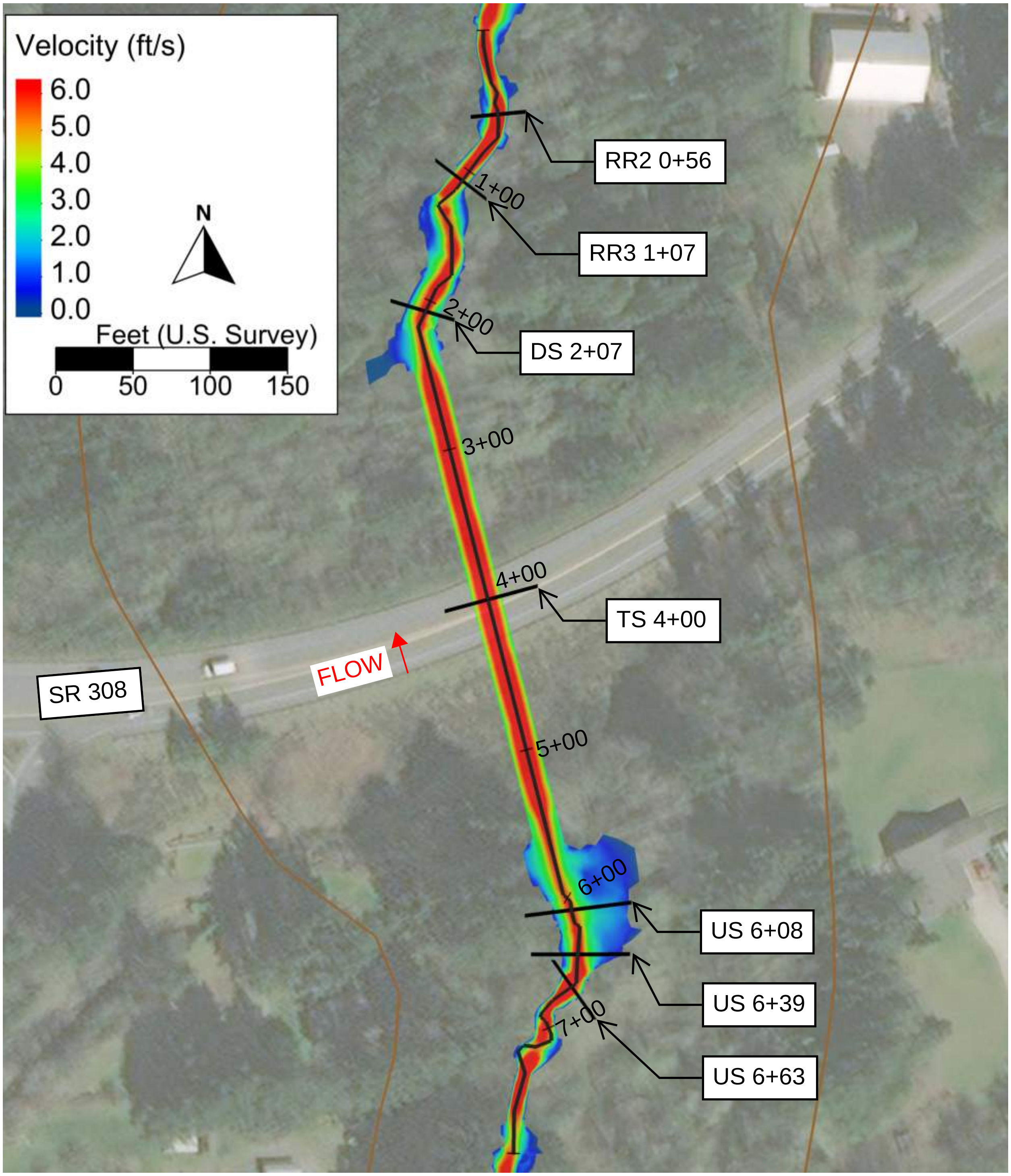
Appendix H.16 - Proposed Conditions 2080 100-year Shear Stress



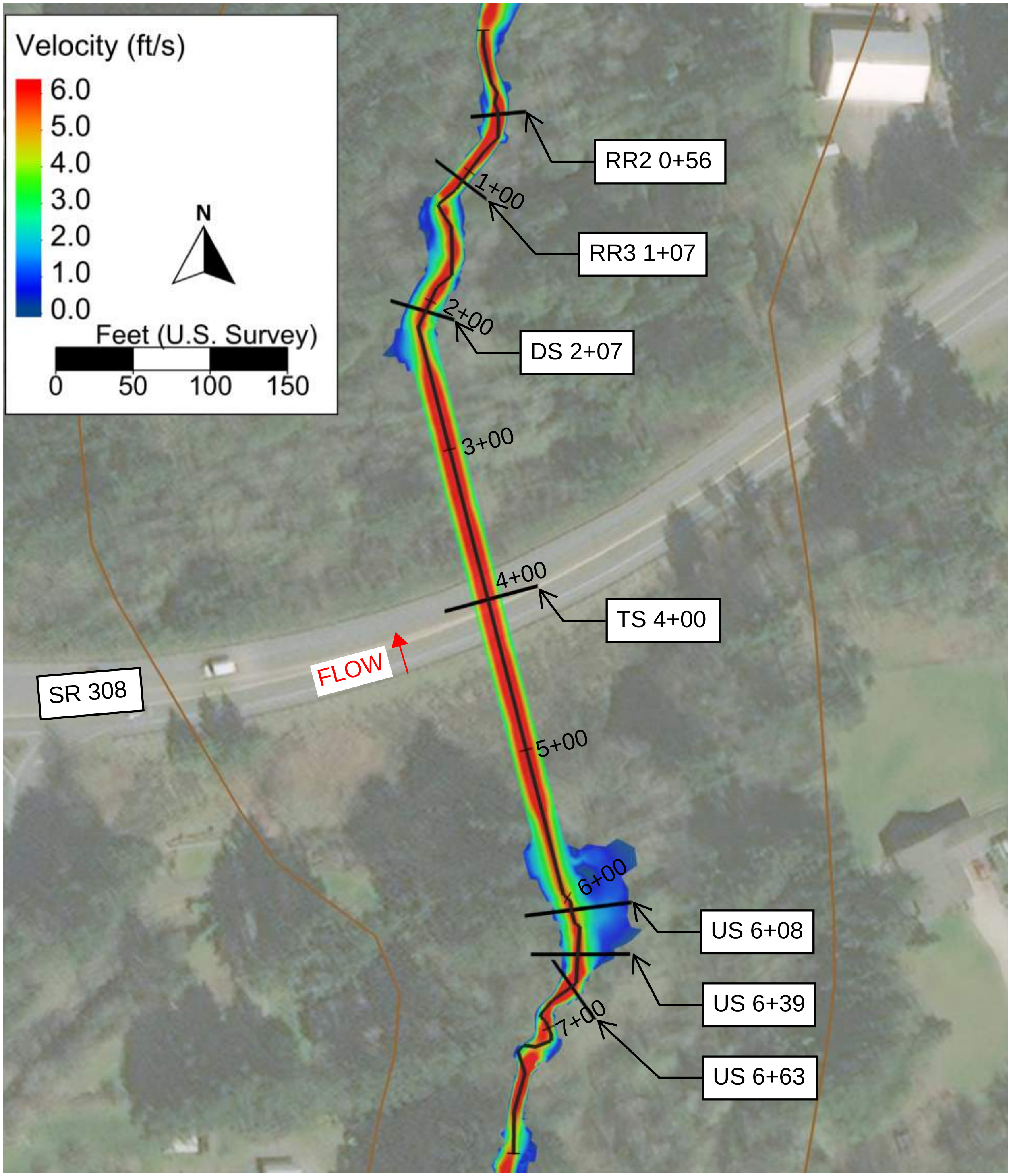
Appendix H.17 - Proposed Conditions 2-year Velocity



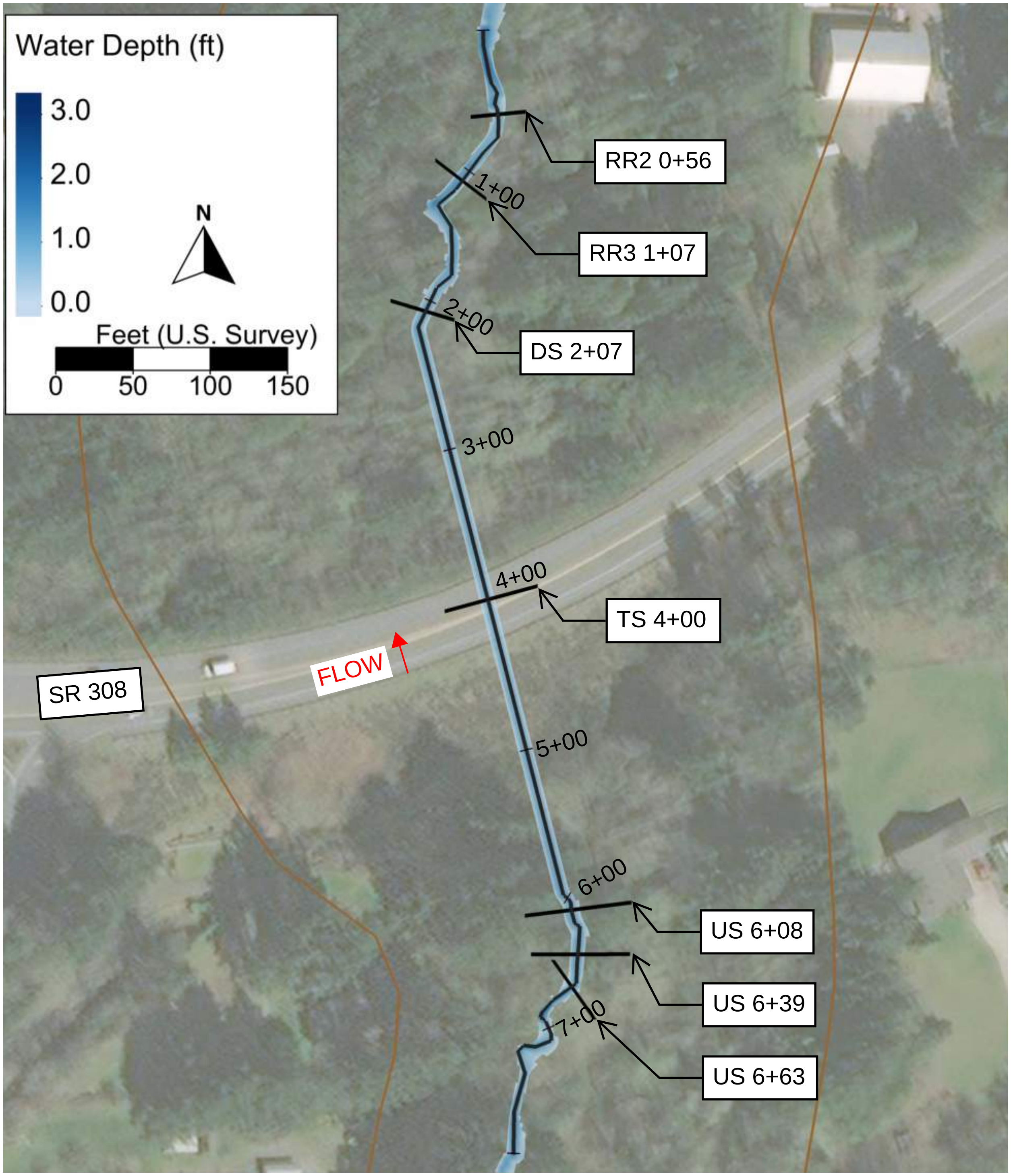
Appendix H.18 - Proposed Conditions 100-year Velocity



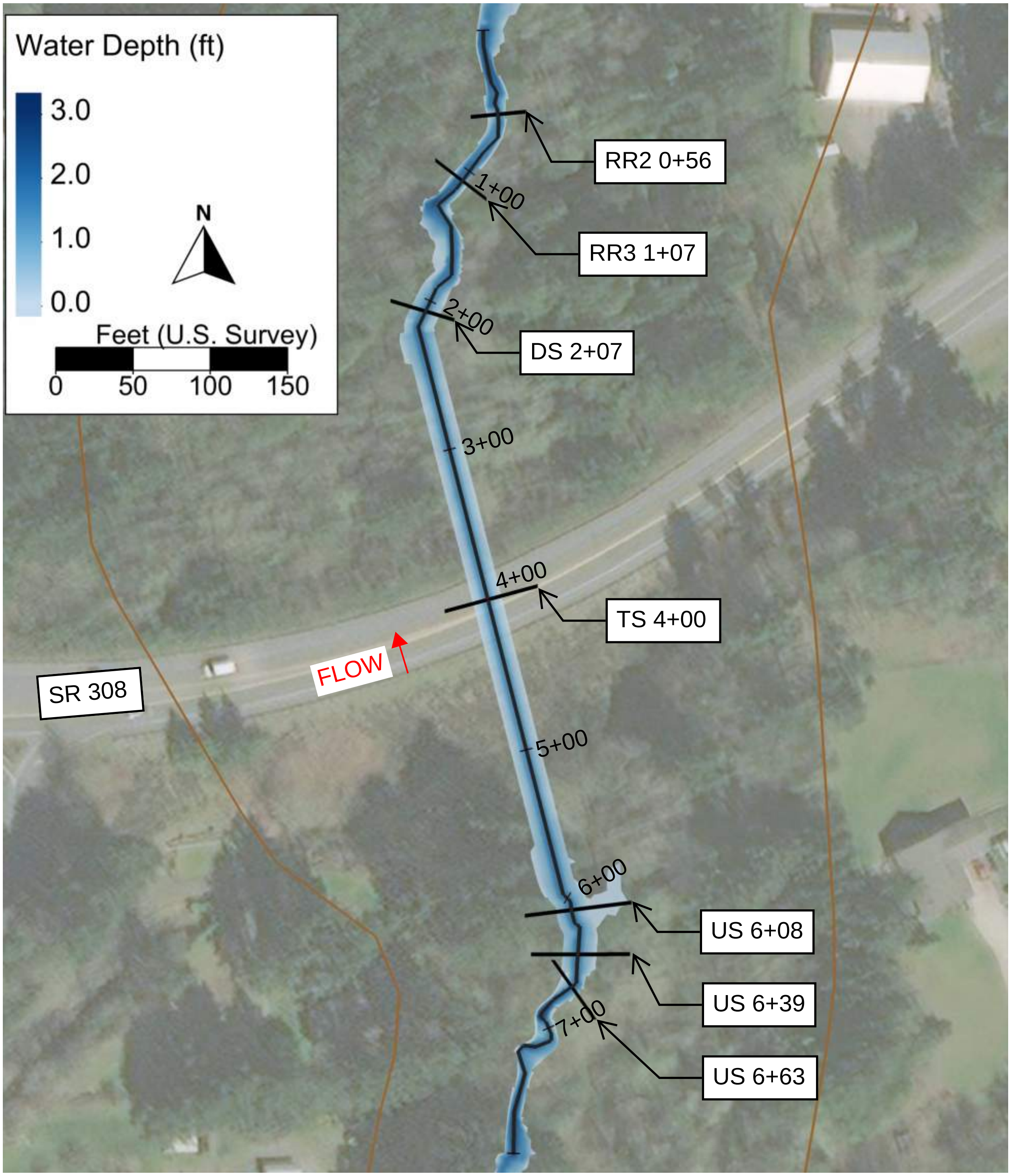
Appendix H.19 - Proposed Conditions 500-year Velocity



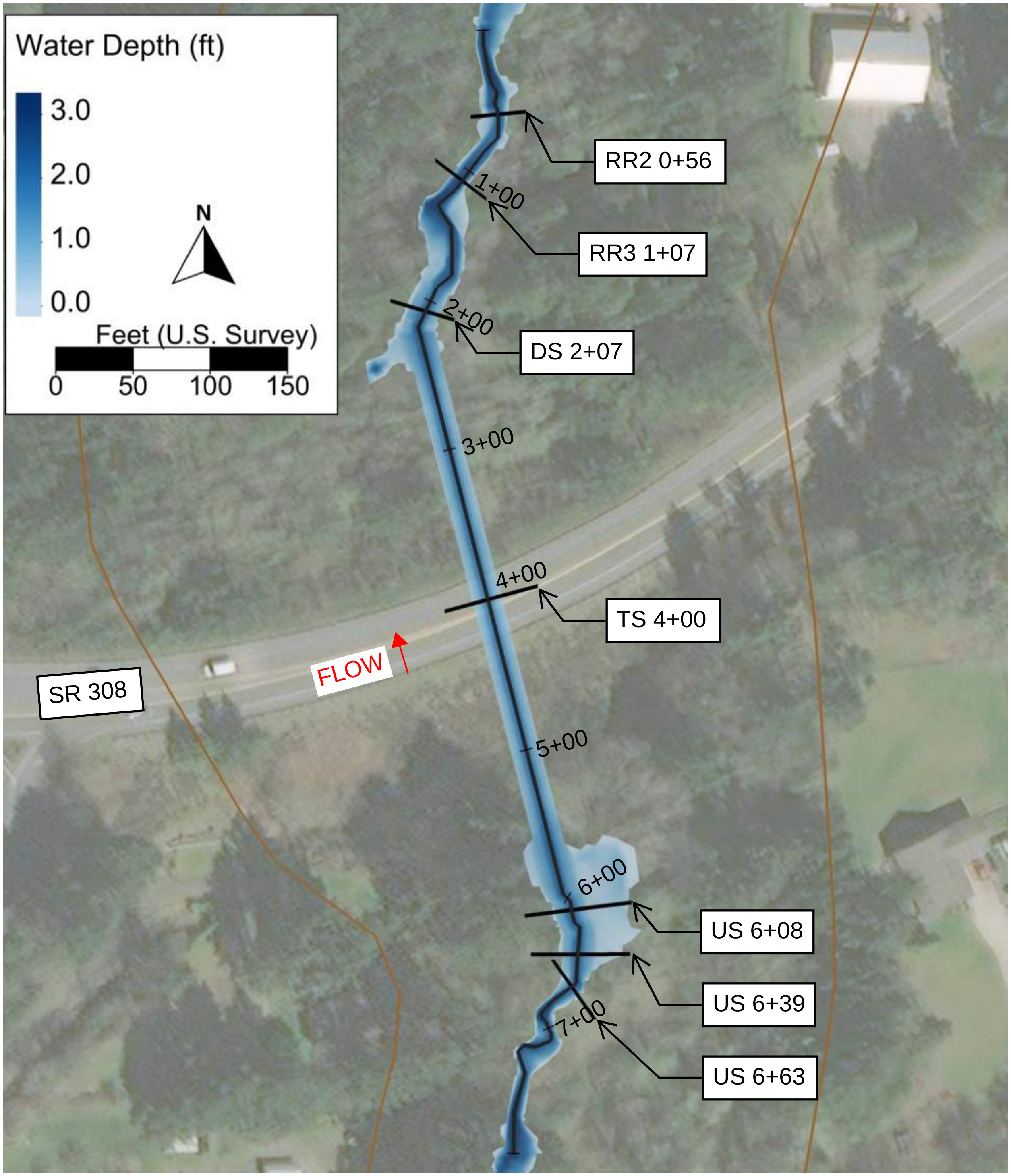
Appendix H.20 - Proposed Conditions 2080 100-year Velocity



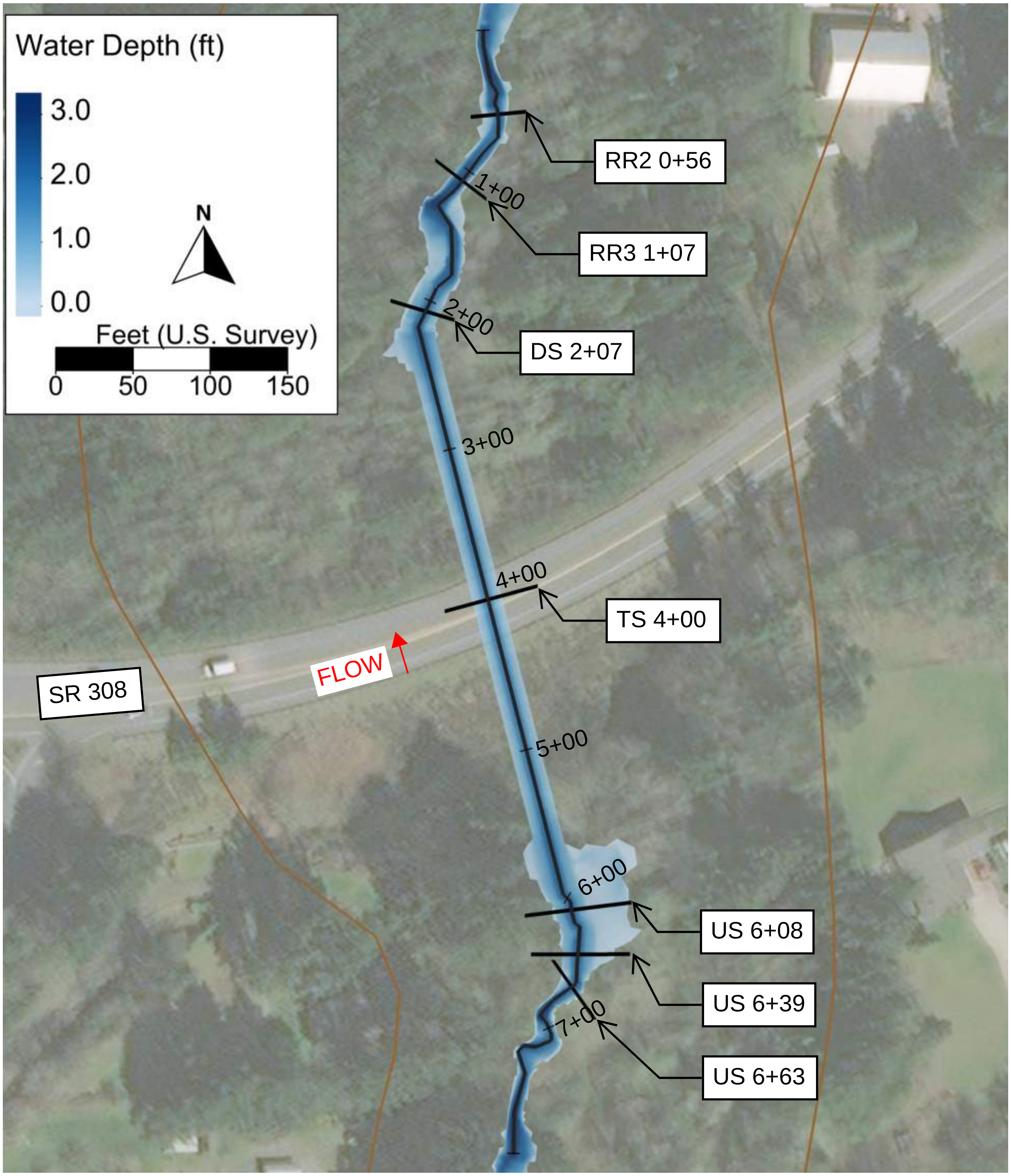
Appendix H.21 - Proposed Conditions 2-year Depth



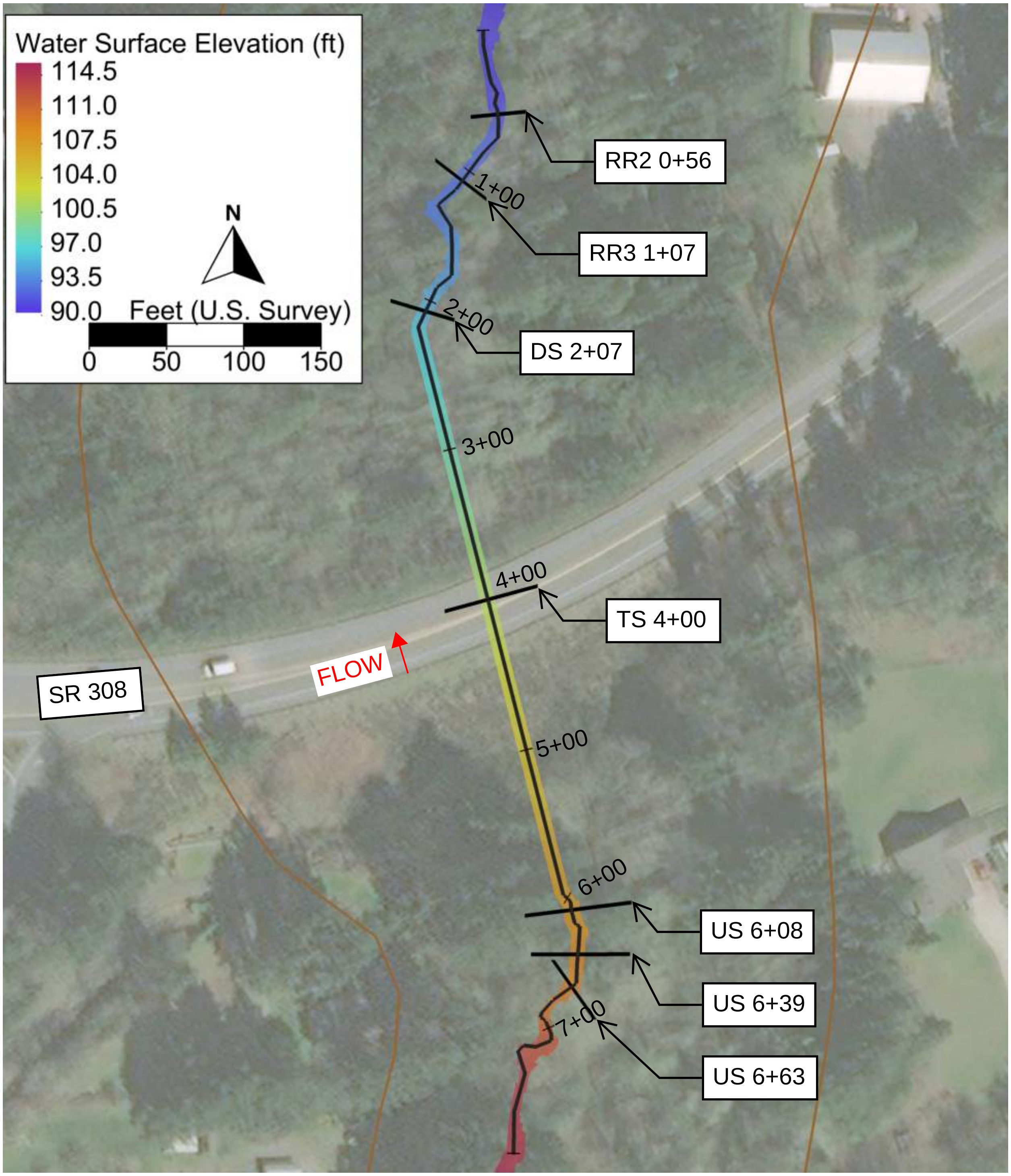
Appendix H.22 - Proposed Conditions 100-year Depth



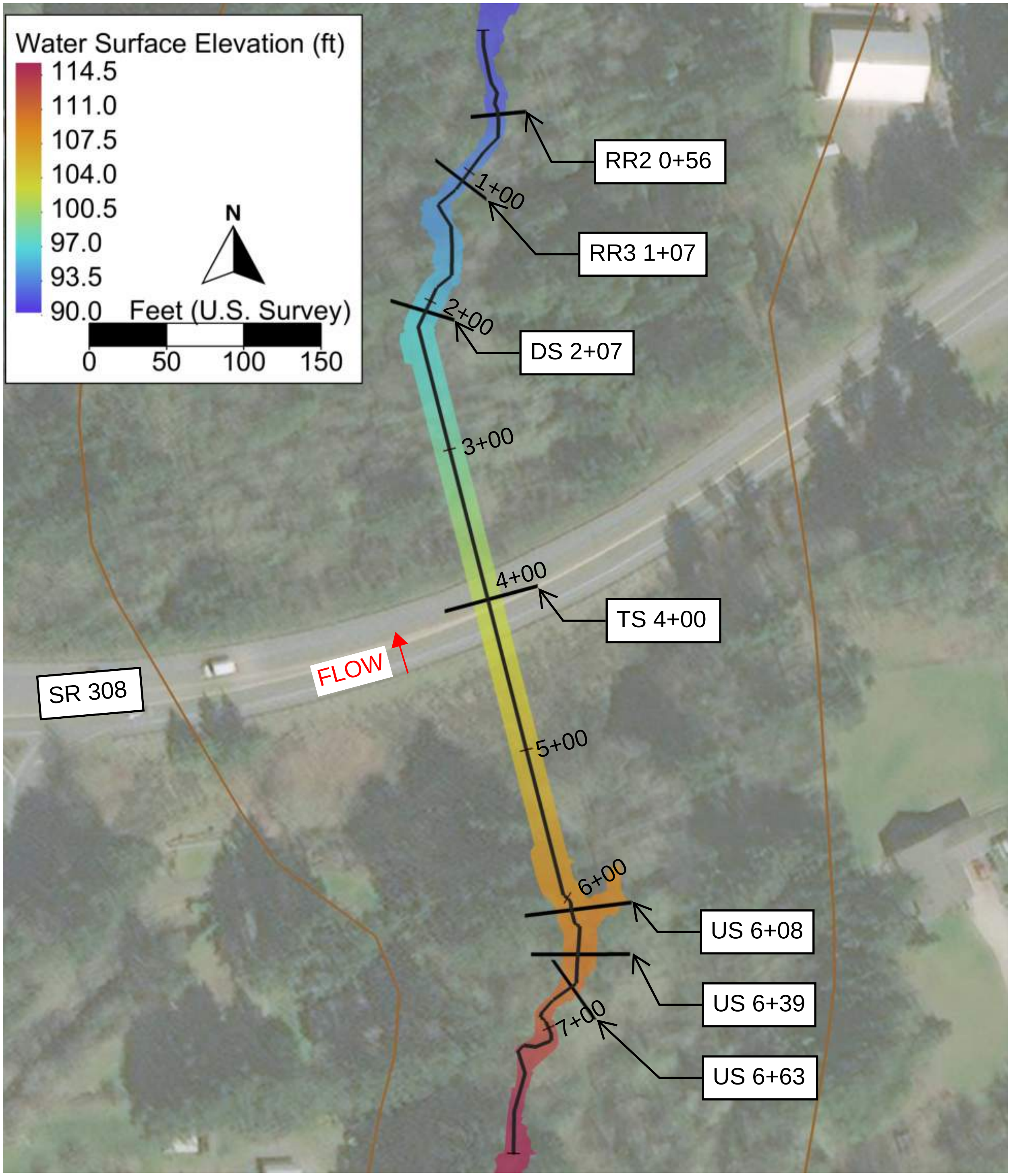
Appendix H.23 - Proposed Conditions 500-year Depth



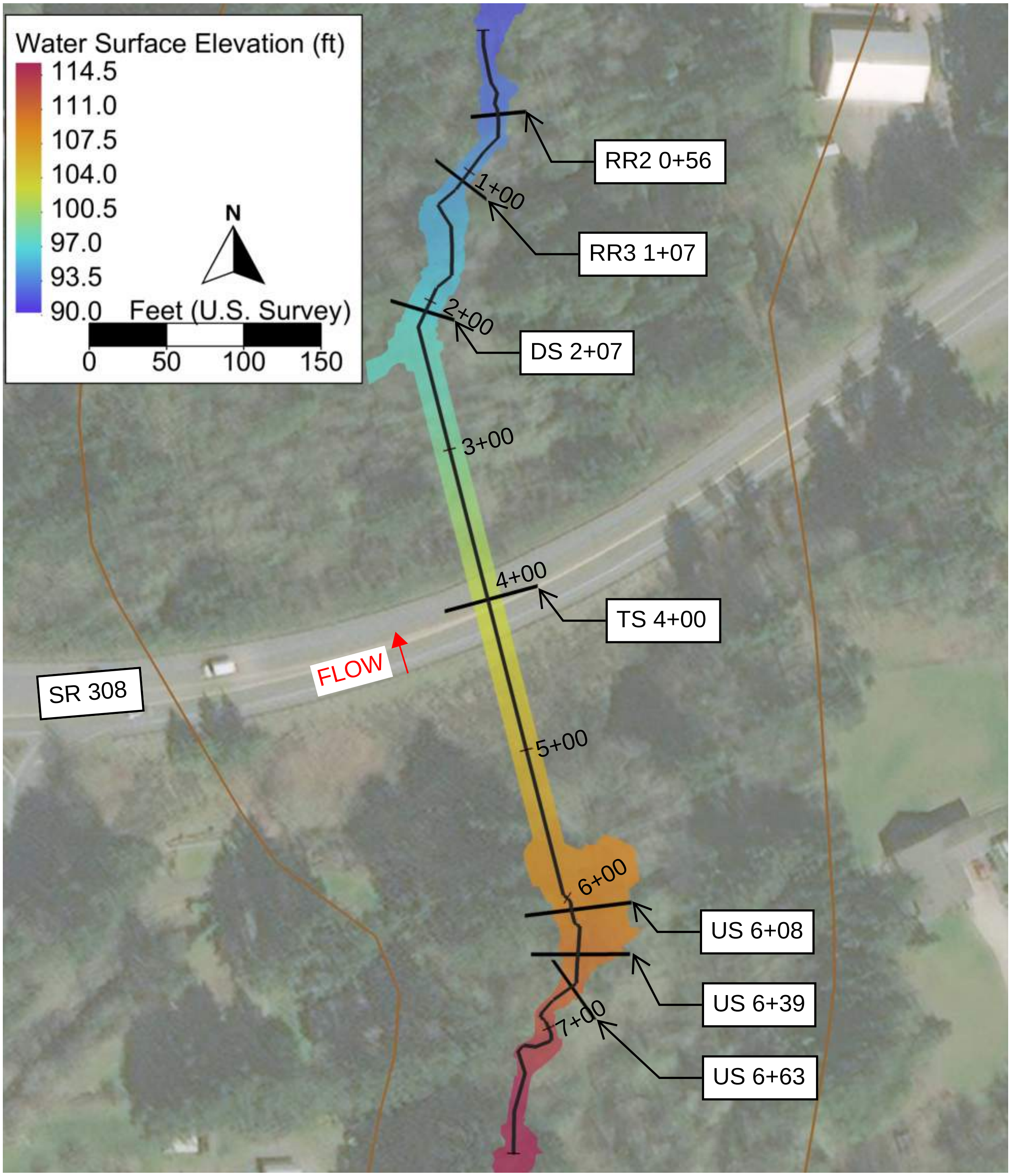
Appendix H.24 - Proposed Conditions 2080 100-year Depth



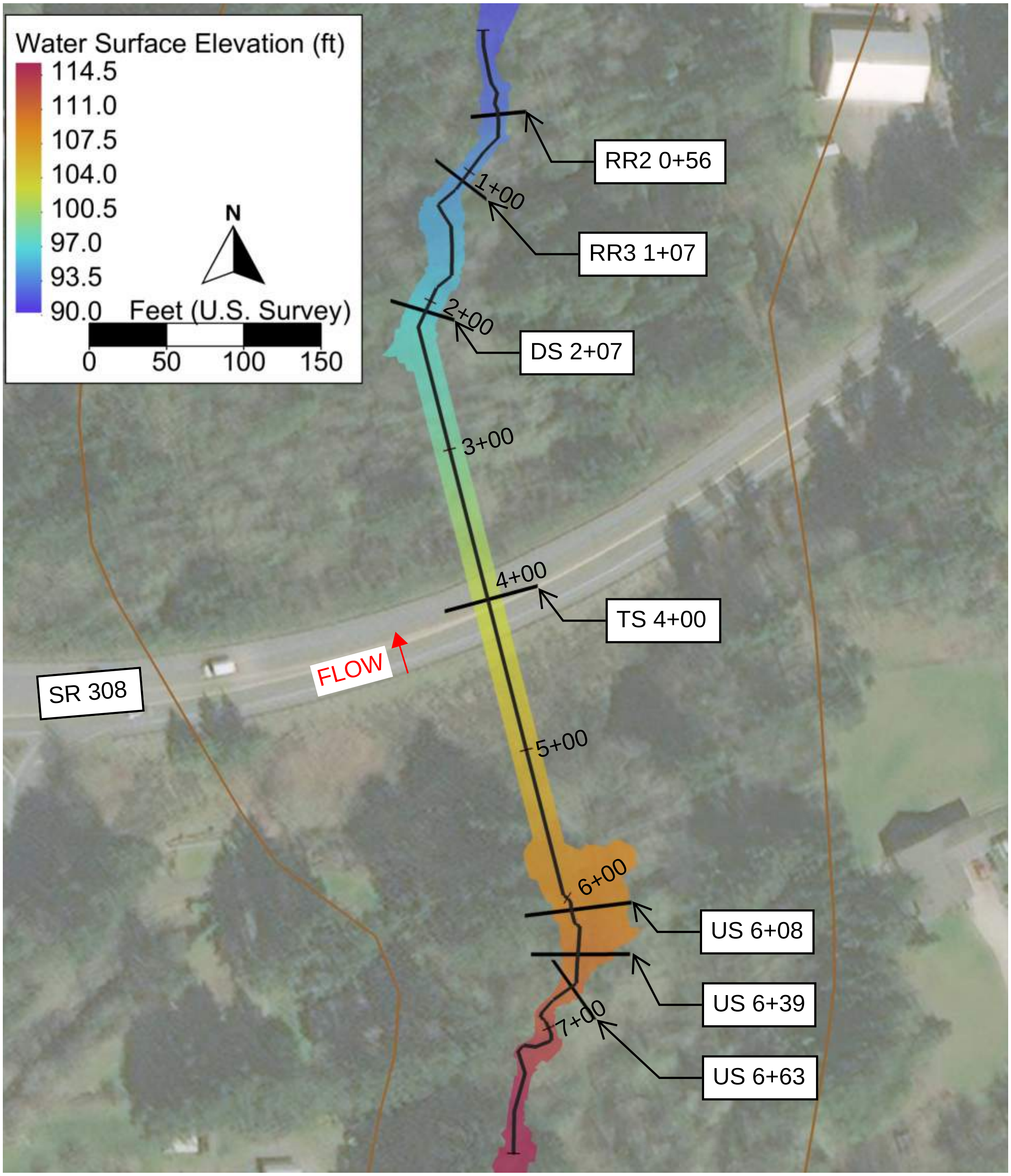
Appendix H.25 - Proposed Conditions 2-year Water Surface Elevation



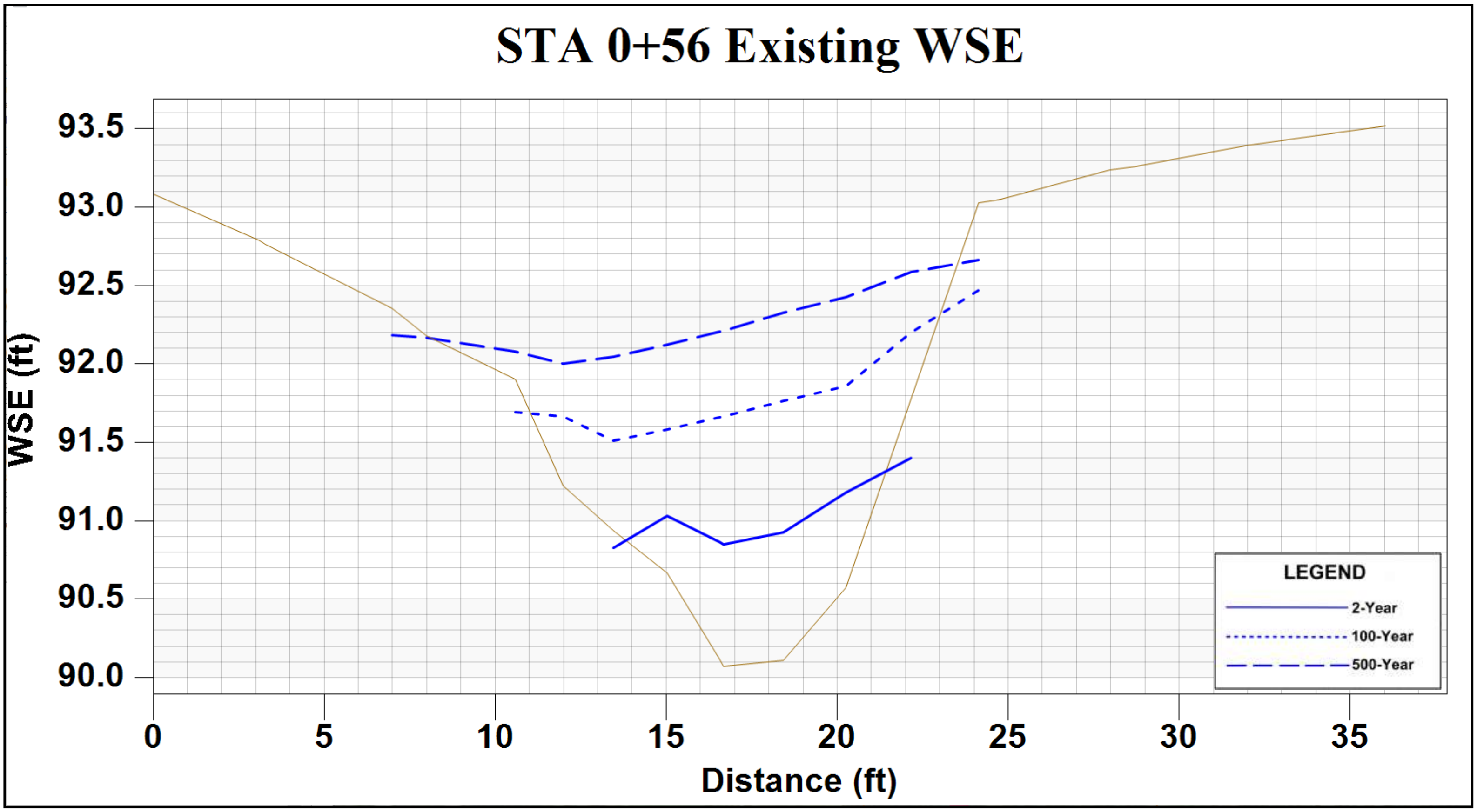
Appendix H.26 - Proposed Conditions 100-year Water Surface Elevation



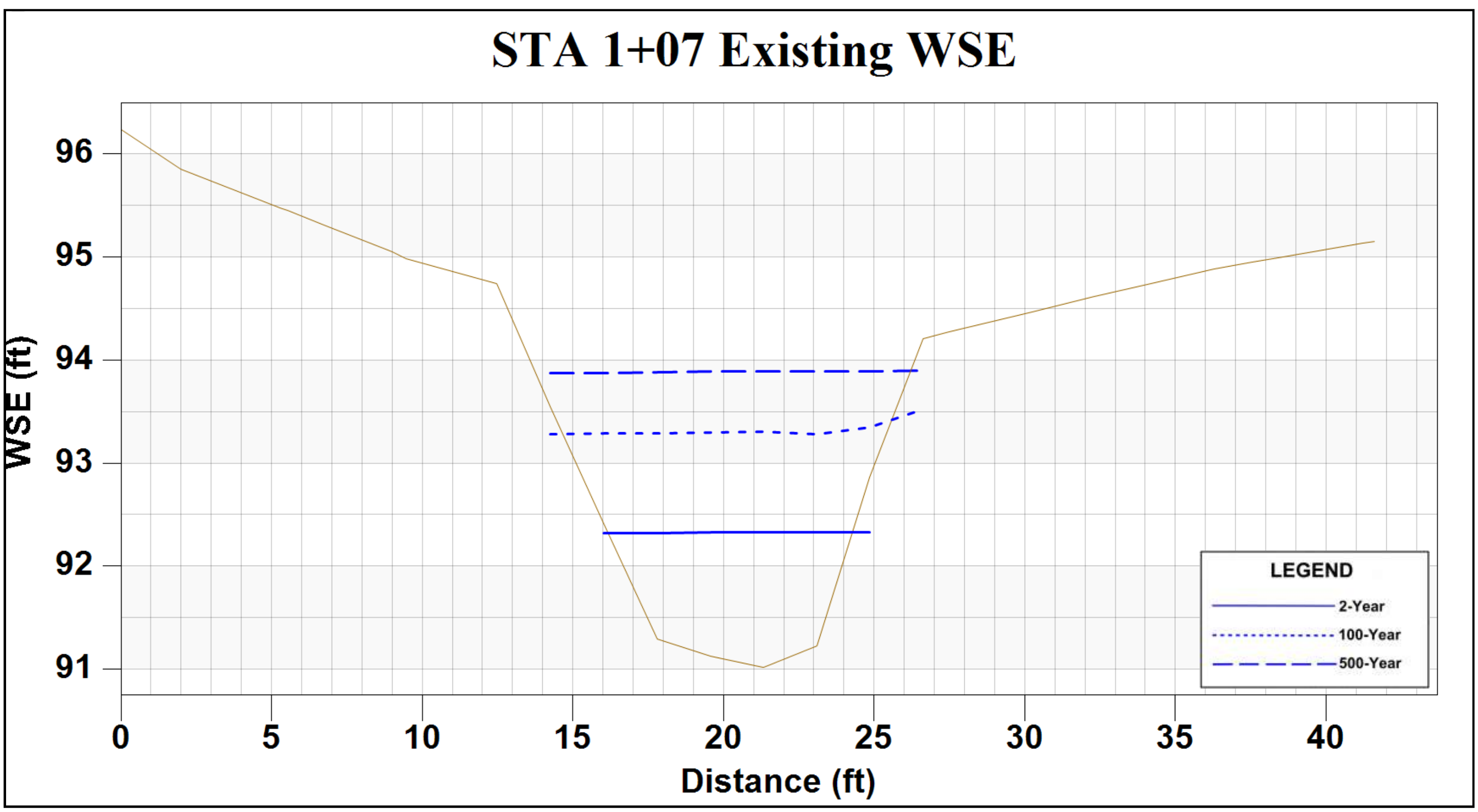
Appendix H.27 - Proposed Conditions 500-year Water Surface Elevation



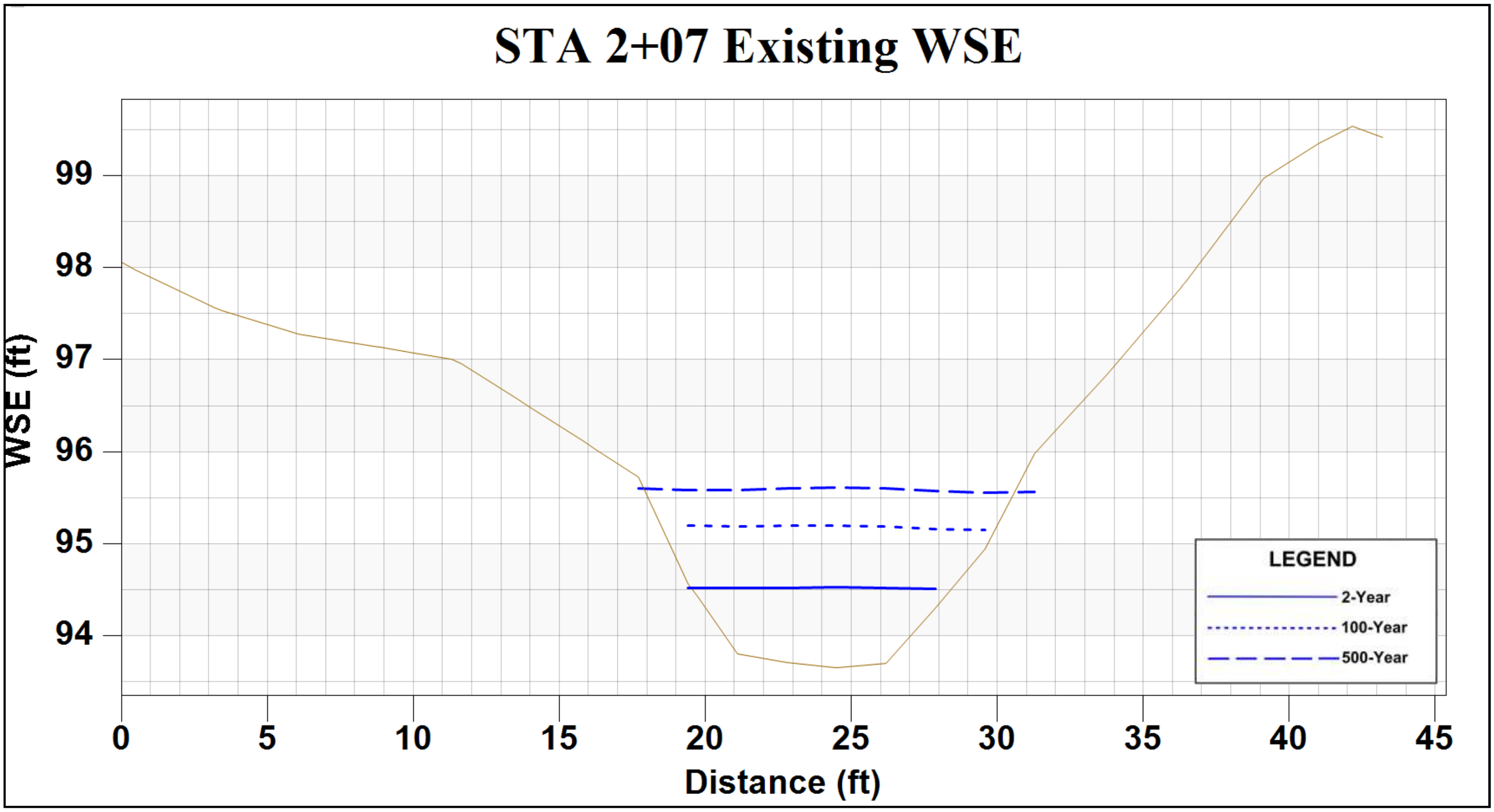
Appendix H.28 - Proposed Conditions 2080 100-year Water Surface Elevation

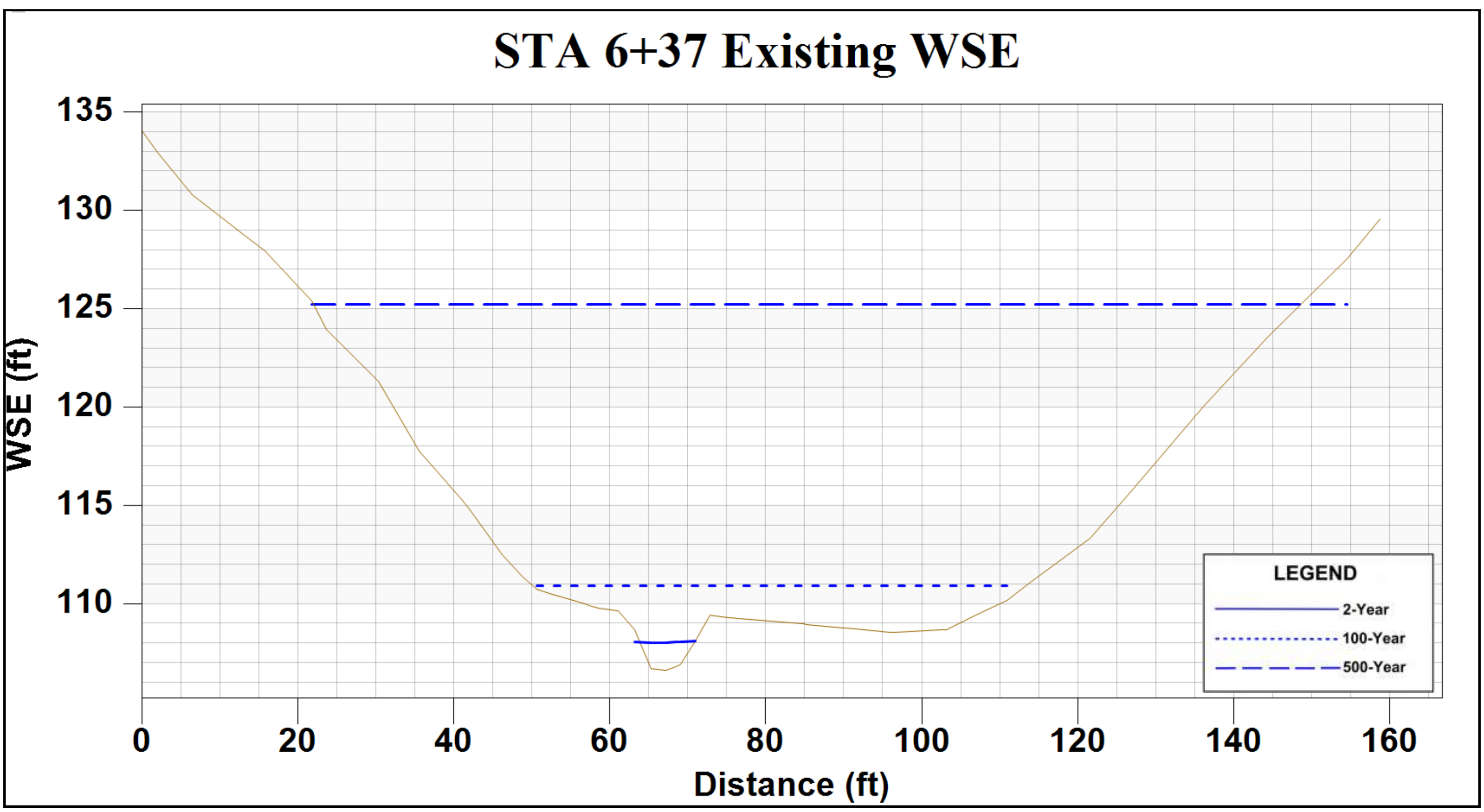


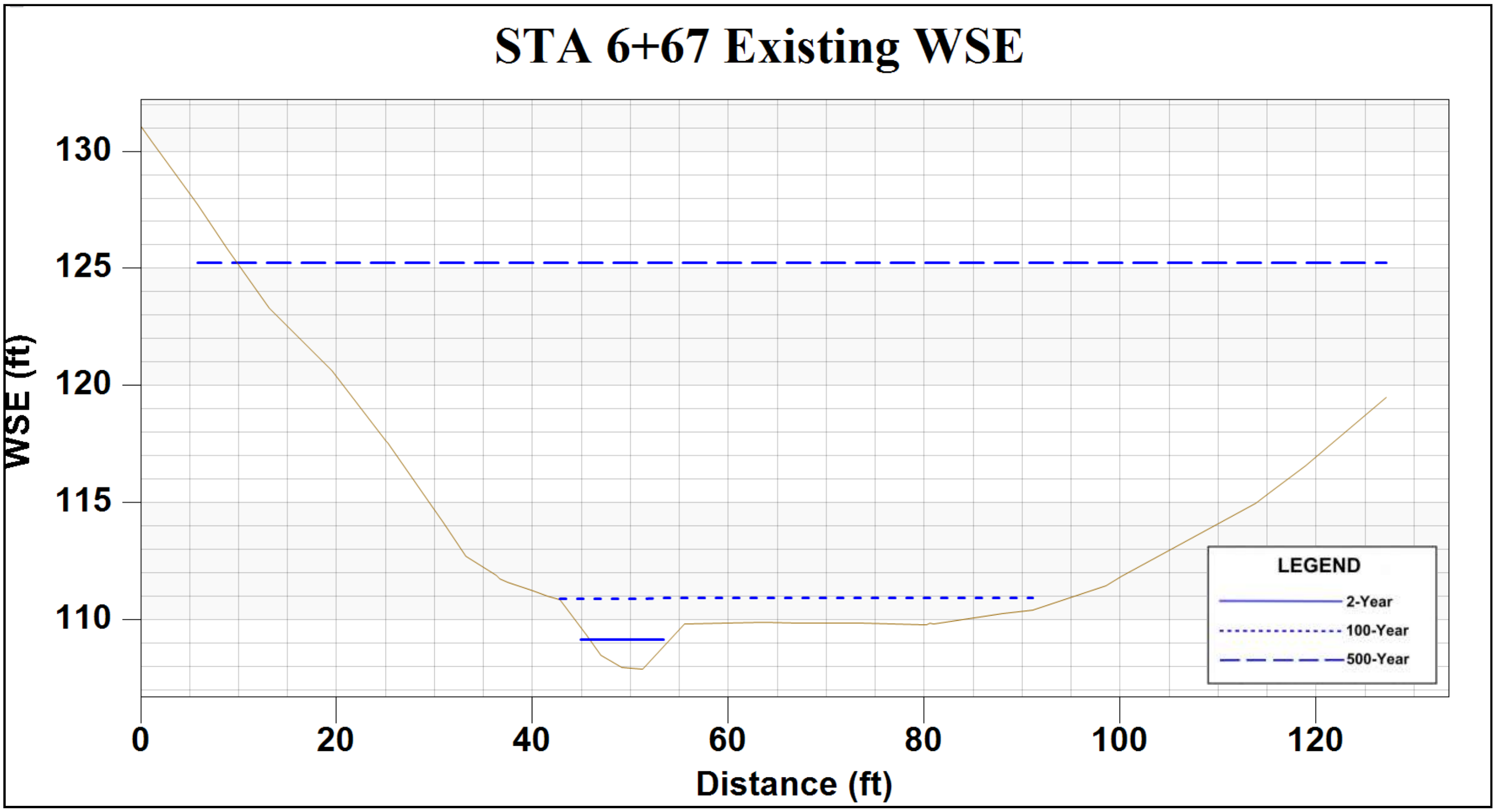
STA 0+56 Existing WSE
WSE (ft)
Distance (ft)
LEGEND
2-Year
100-Year
500-Year
93.5
93.0
92.5
92.0
91.5
91.0
90.5
90.0
0
5
10
15
20
25
30
35

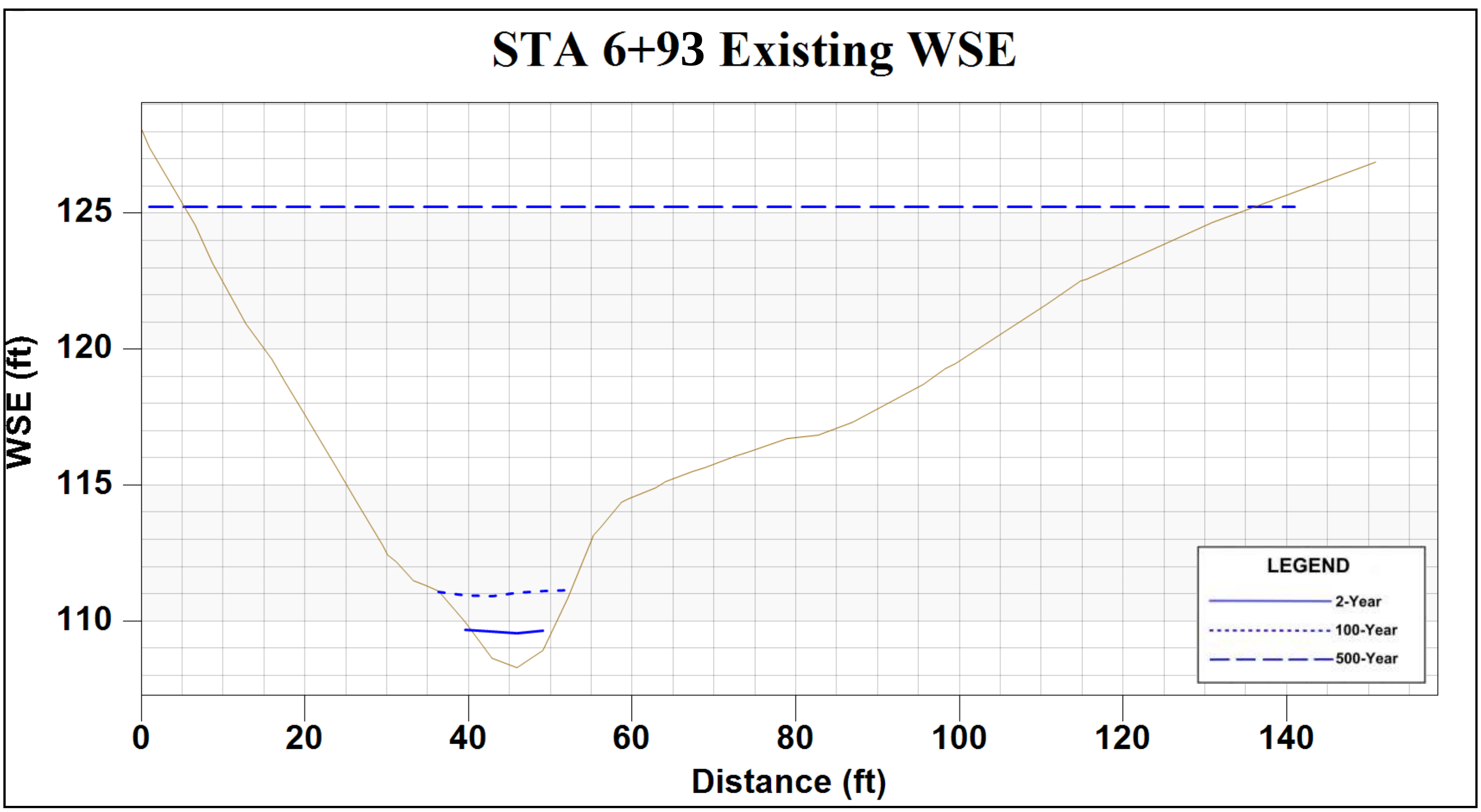


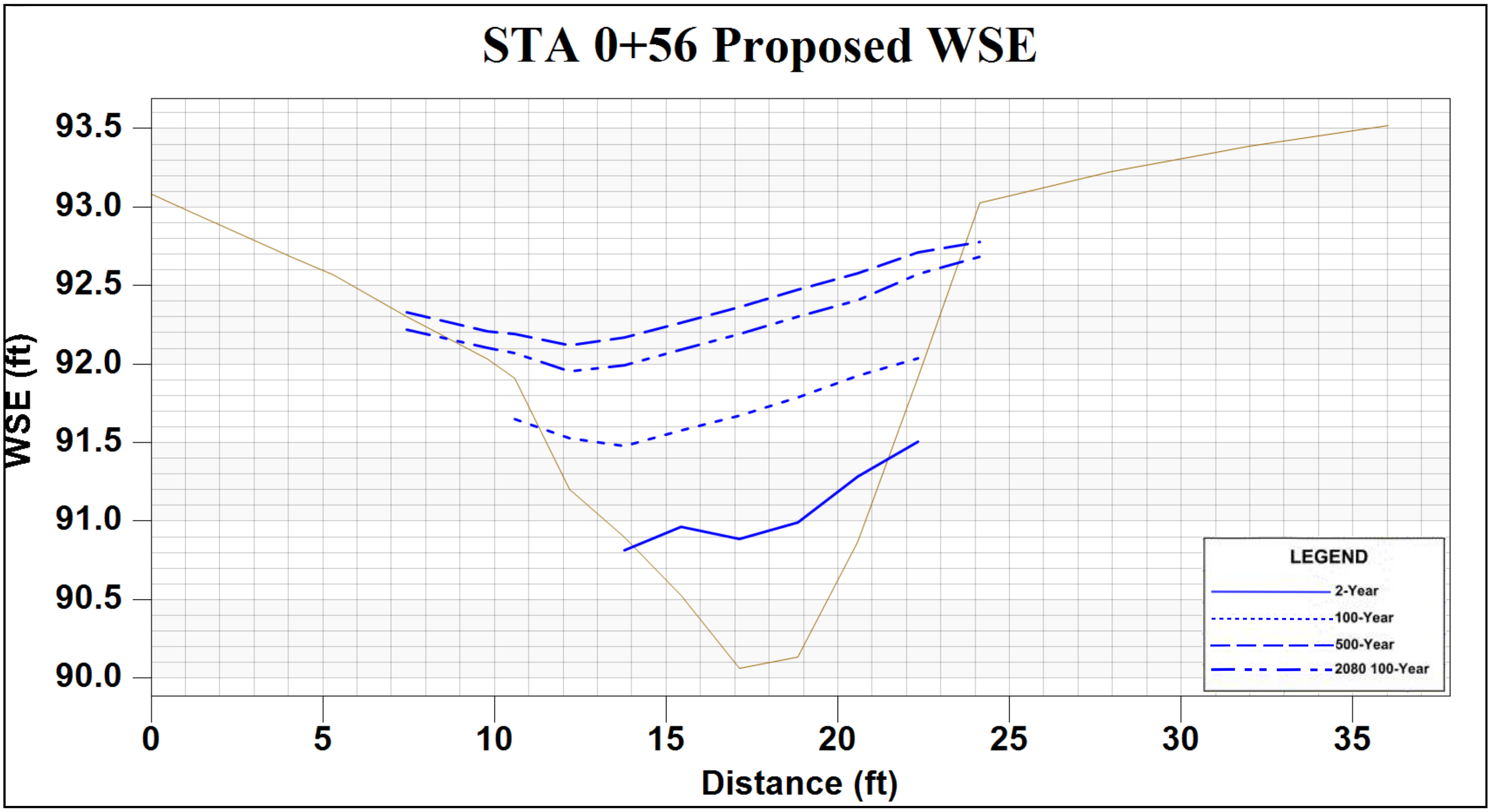
STA 1+07 Existing WSE
WSE (ft)
Distance (ft)
LEGEND
2-Year
100-Year
500-Year
96
95
94
93
92
91
0
5
10
15
20
25
30
35
40


STA 2+07 Existing WSE
WSE (ft)
99
98
97
96
95
94
0
5
10
15
20
25
30
35
40
45
Distance (ft)
LEGEND
2-Year
100-Year
500-Year

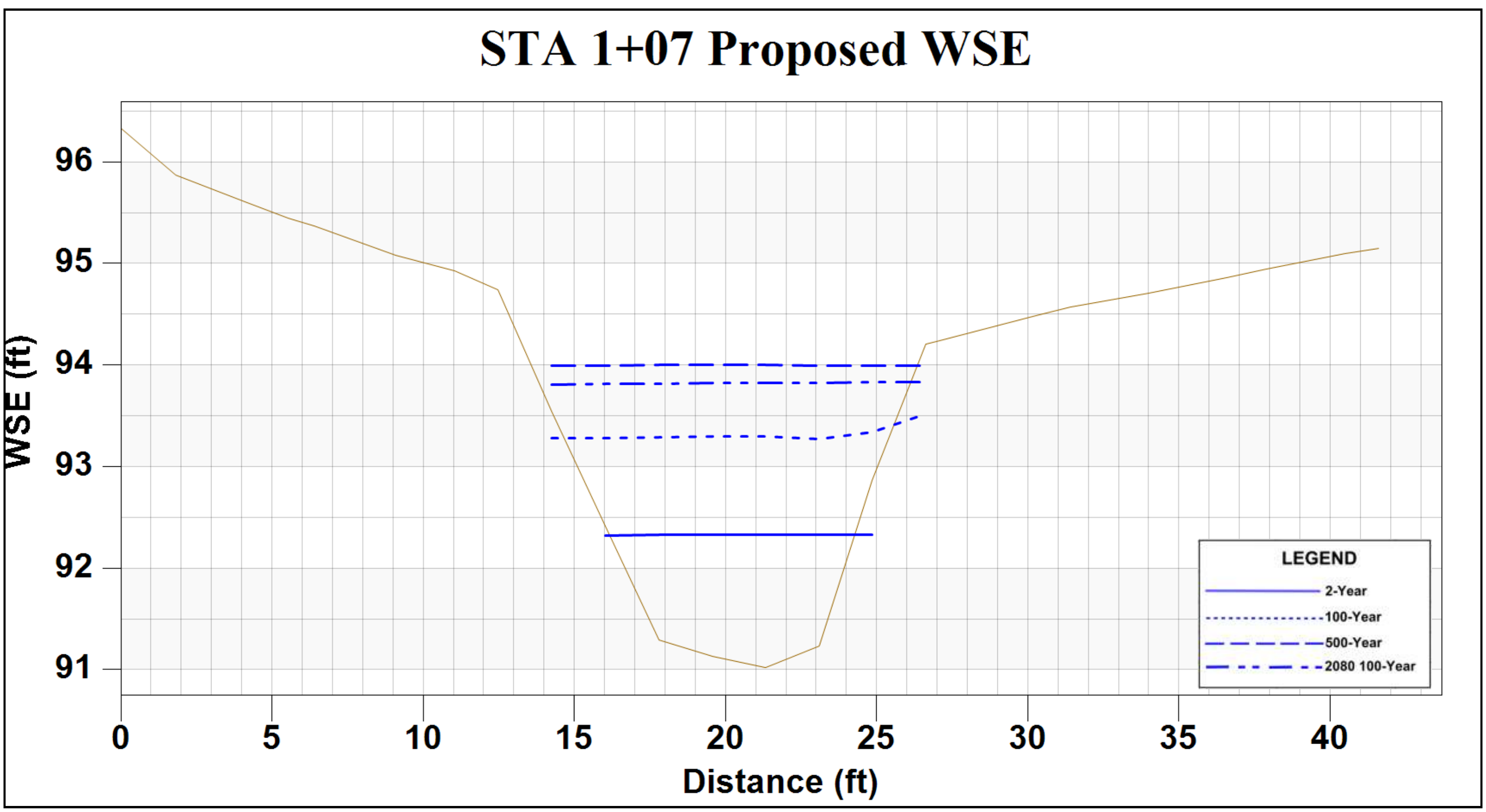

STA 6+37 Existing WSE
WSE (ft)
135
130
125
120
115
110
0
20
40
60
80
100
120
140
160
Distance (ft)
LEGEND
2-Year
100-Year
500-Year


STA 6+67 Existing WSE
WSE (ft)
Distance (ft)
130
125
120
115
110
0
20
40
60
80
100
120
LEGEND
2-Year
100-Year
500-Year

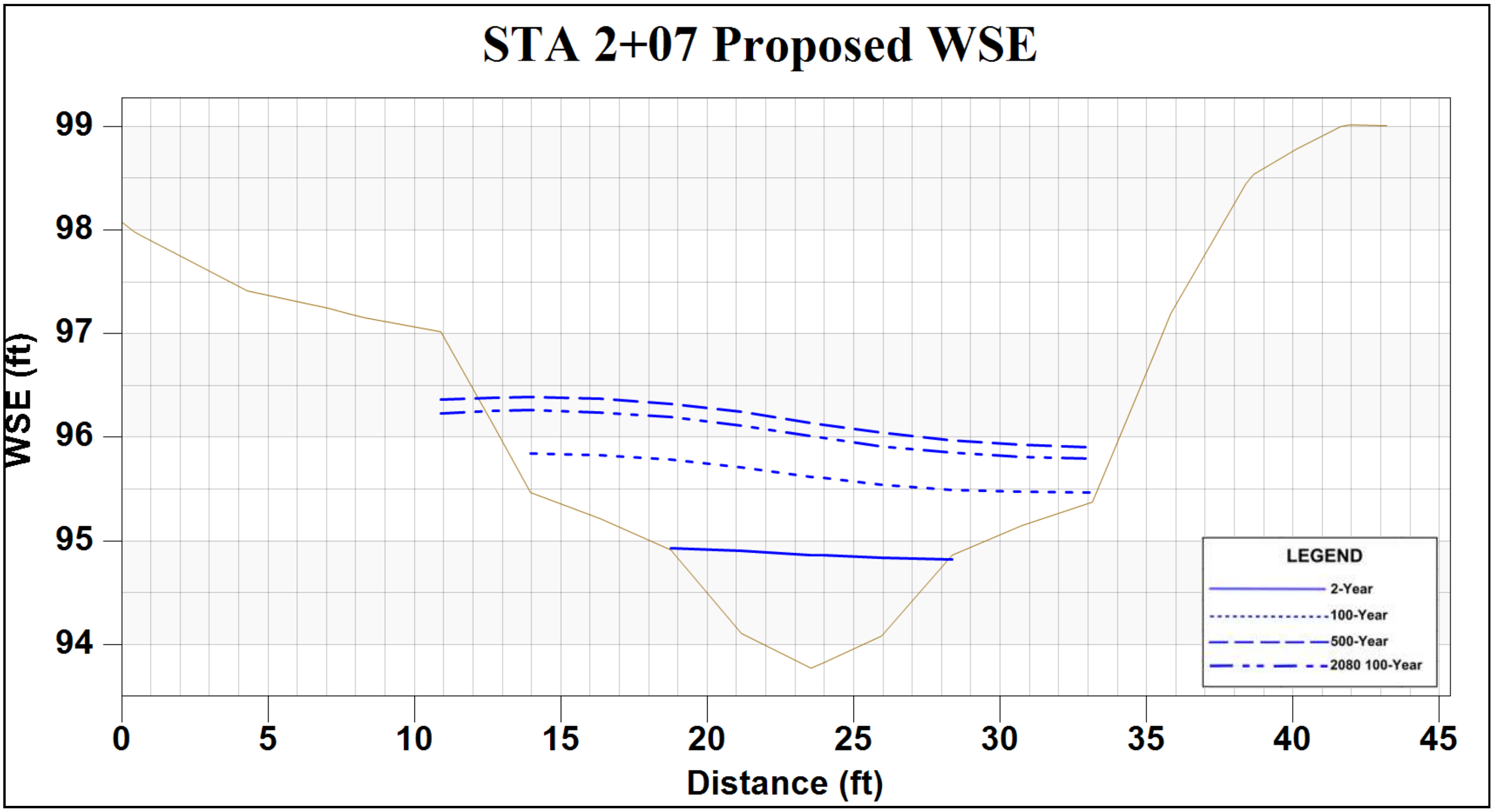

STA 6+93 Existing WSE
WSE (ft)
Distance (ft)
125
120
115
110
0
20
40
60
80
100
120
140
LEGEND
2-Year
100-Year
500-Year

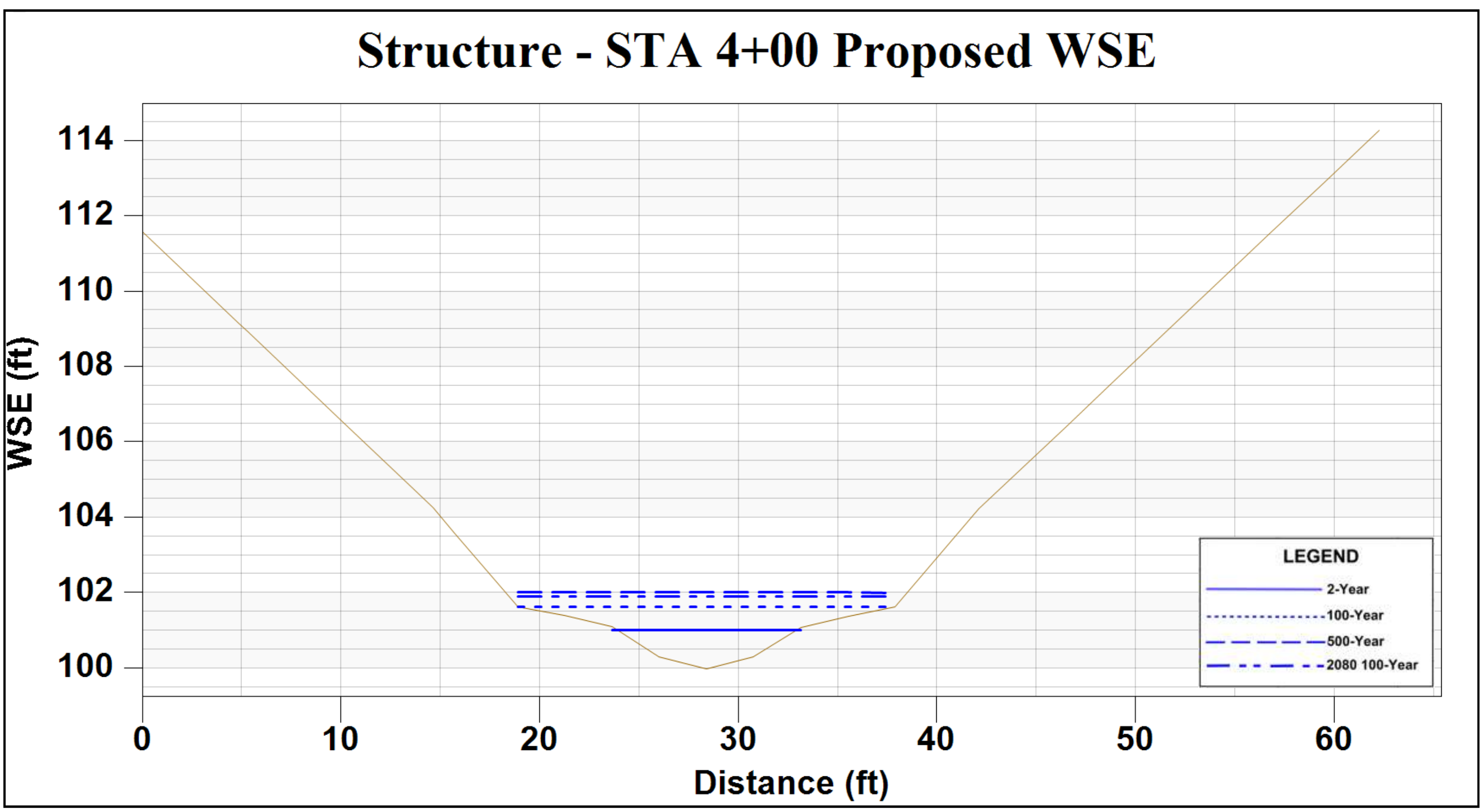


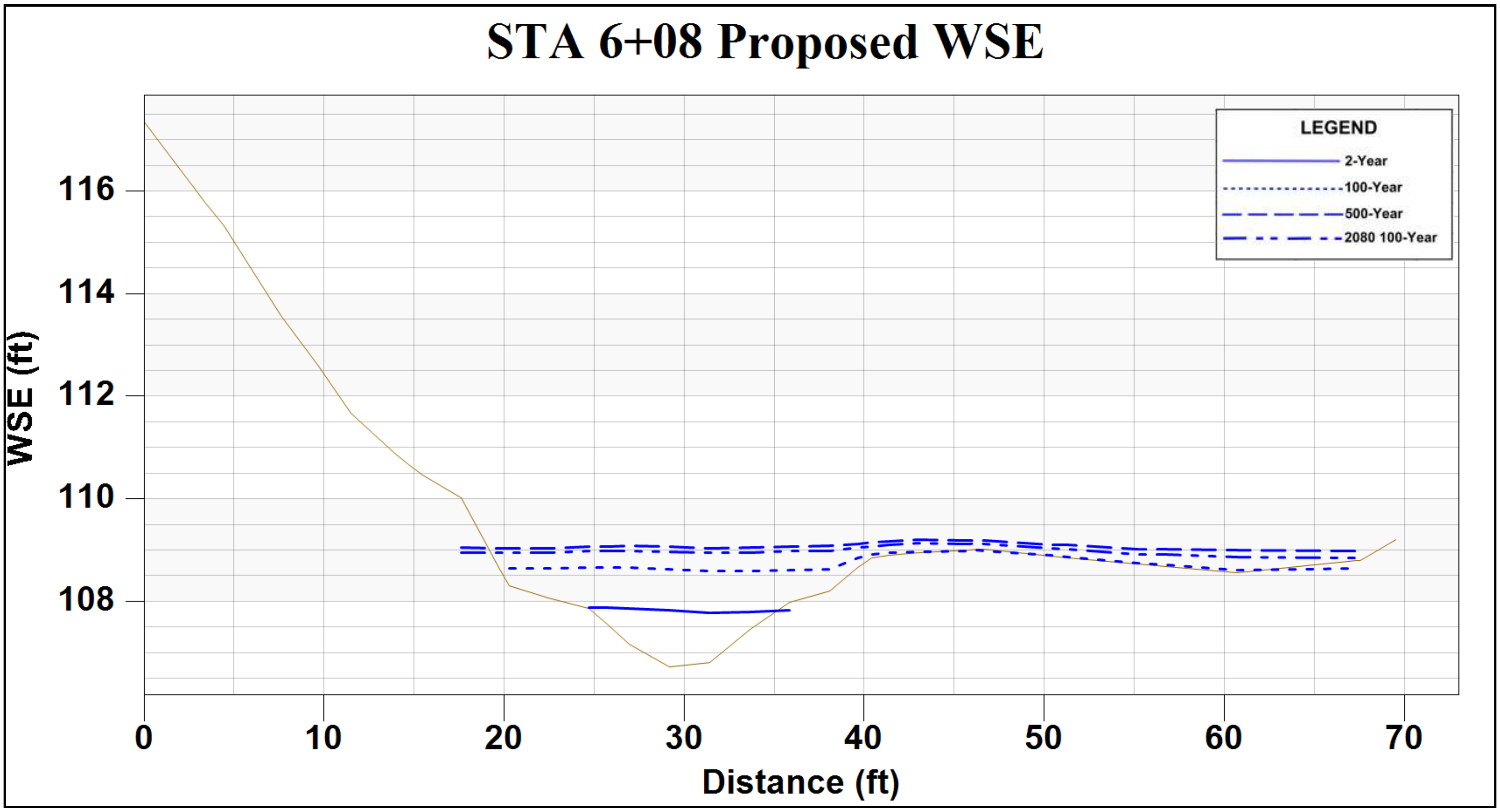
STA 0+56 Proposed WSE
WSE (ft)
93.5
93.0
92.5
92.0
91.5
91.0
90.5
90.0
0
5
10
15
20
25
30
35
Distance (ft)
LEGEND
2-Year
100-Year
500-Year
2080 100-Year

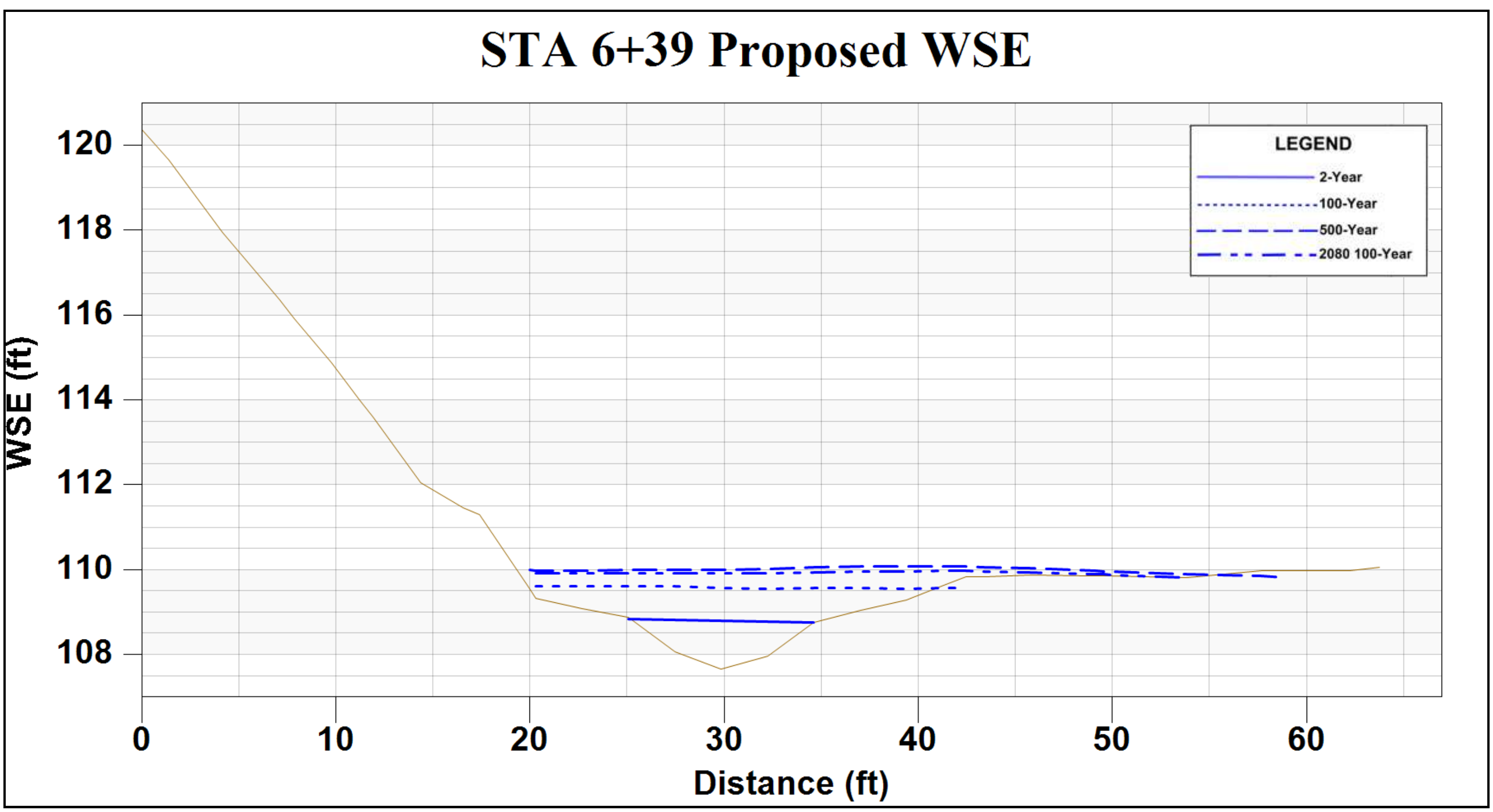


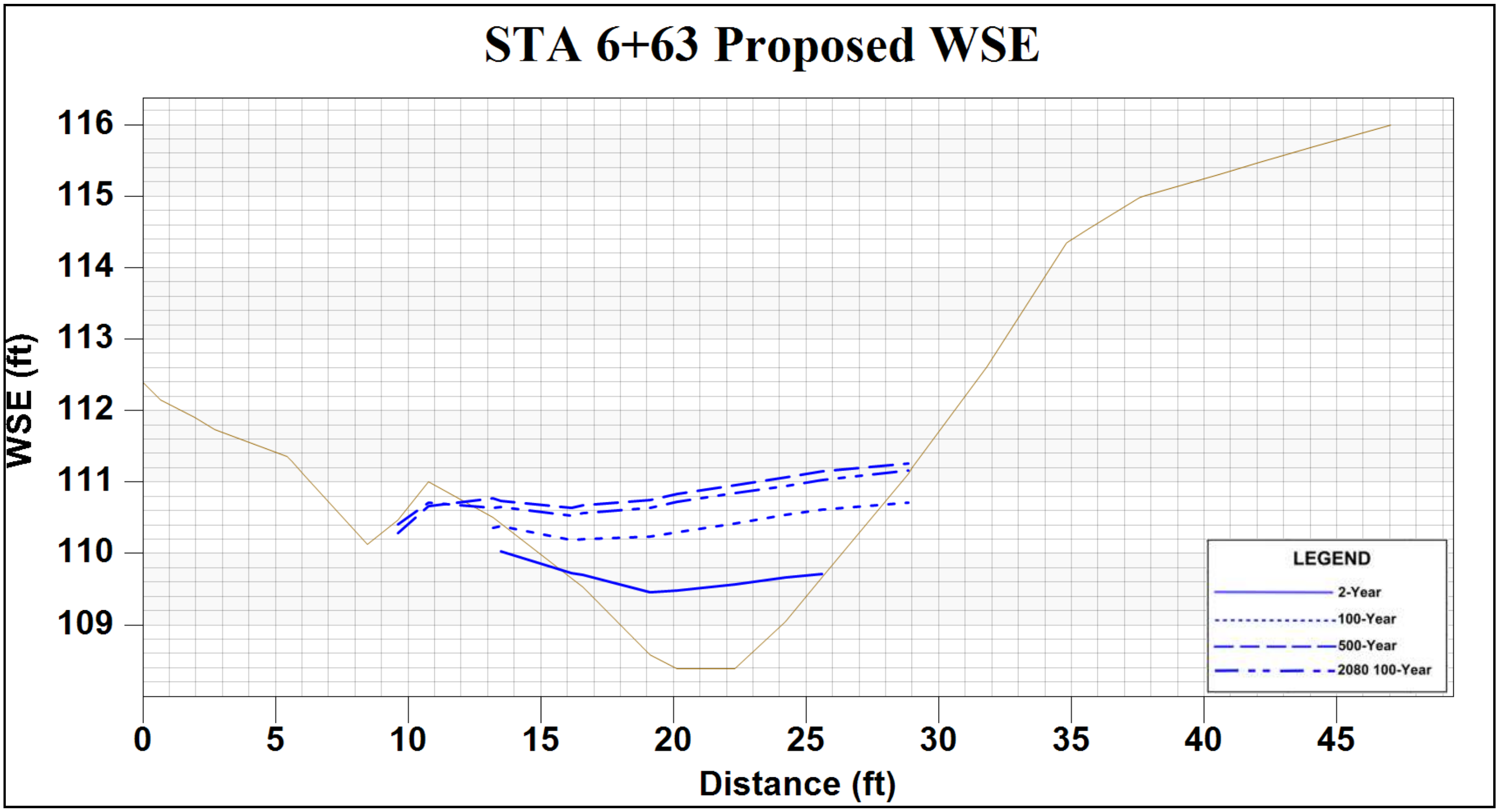
STA 1+07 Proposed WSE
WSE (ft)
96
95
94
93
92
91
0
5
10
15
20
25
30
35
40
Distance (ft)
LEGEND
2-Year
100-Year
500-Year
2080 100-Year


STA 2+07 Proposed WSE
WSE (ft)
99
98
97
96
95
94
0
5
10
15
20
25
30
35
40
45
Distance (ft)
LEGEND
2-Year
100-Year
500-Year
2080 100-Year

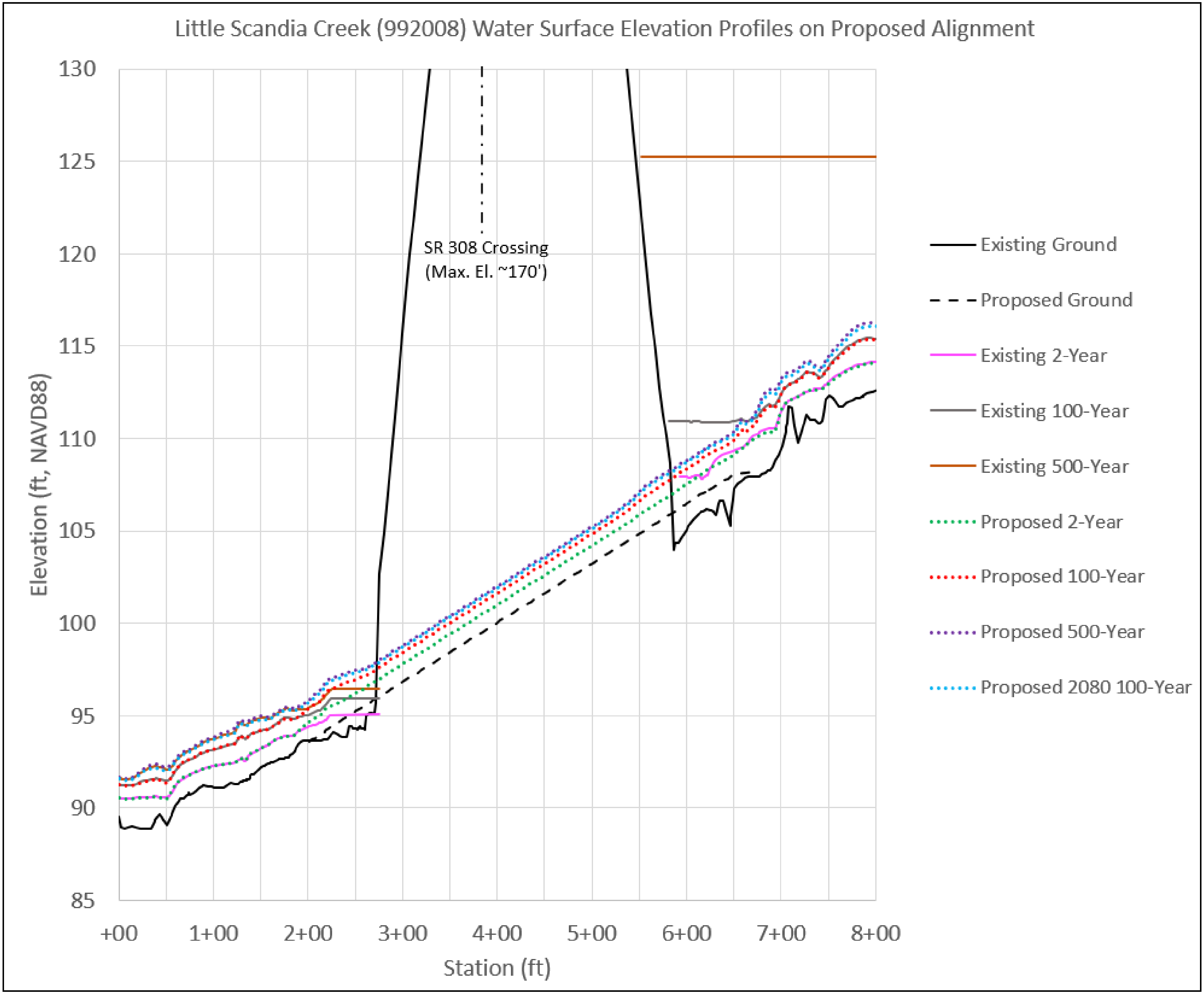

Structure - STA 4+00 Proposed WSE
WSE (ft)
114
112
110
108
106
104
102
100
0
10
20
30
40
50
60
Distance (ft)
LEGEND
2-Year
100-Year
500-Year
2080 100-Year


STA 6+08 Proposed WSE
LEGEND
2-Year
100-Year
500-Year
2080 100-Year
WSE (ft)
116
114
112
110
108
0
10
20
30
40
50
60
70
Distance (ft)


STA 6+39 Proposed WSE
LEGEND
2-Year
100-Year
500-Year
2080 100-Year
WSE (ft)
120
118
116
114
112
110
108
0
10
20
30
40
50
60
Distance (ft)



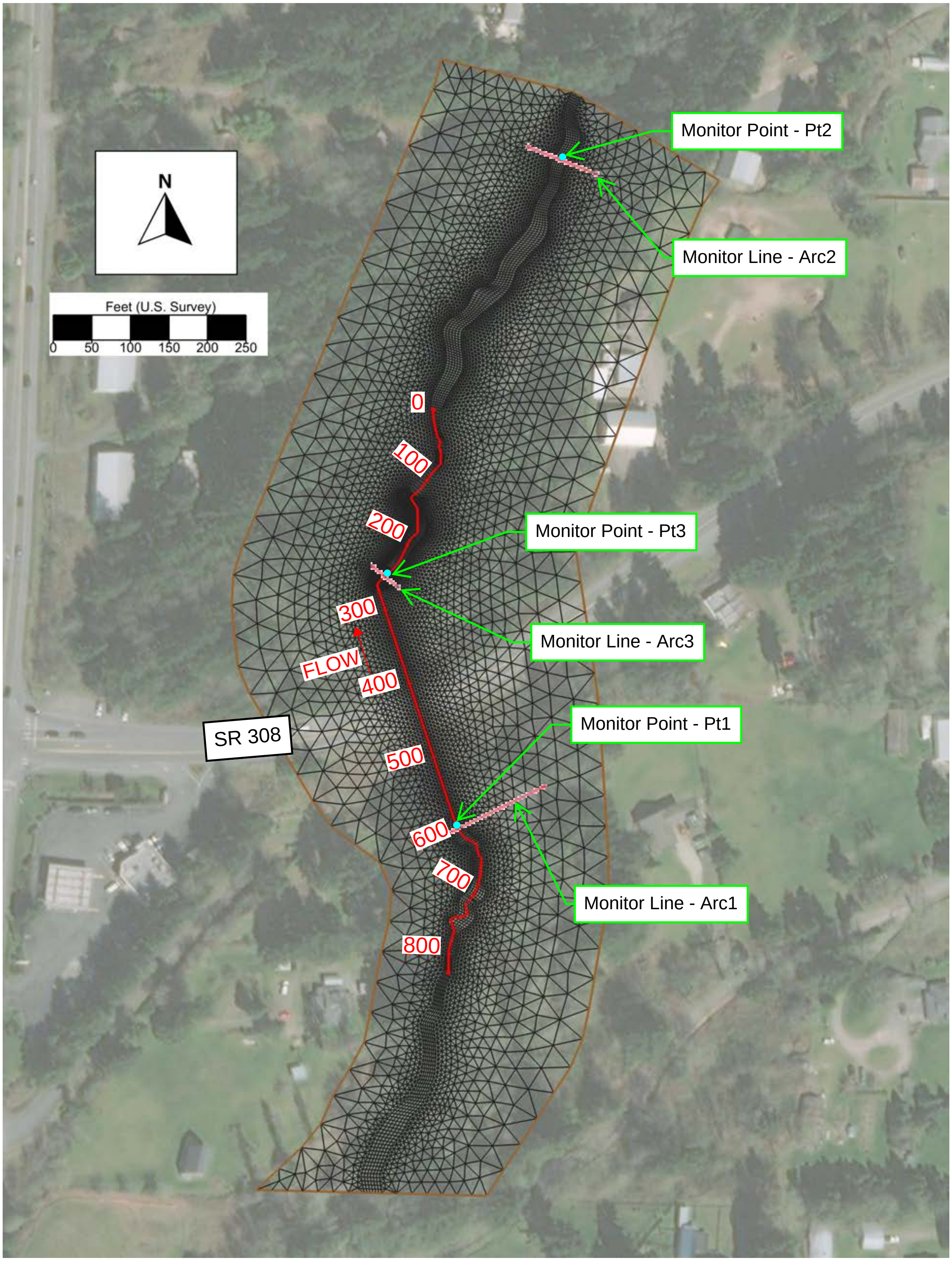
STA 6+63 Proposed WSE
WSE (ft)
116
115
114
113
112
111
110
109
0
5
10
15
20
25
30
35
40
45
Distance (ft)
LEGEND
2-Year
100-Year
500-Year
2080 100-Year



Little Scandia Creek (992008) Water Surface Elevation Profiles on Proposed Alignment
130
125
120
115
110
105
100
95
90
85
Elevation (ft, NAVD88)
SR 308 Crossing
(Max. El. ~170')
+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
8+00
Station (ft)
Existing Ground
Proposed Ground
Existing 2-Year
Existing 100-Year
Existing 500-Year
Proposed 2-Year
Proposed 100-Year
Proposed 500-Year
Proposed 2080 100-Year

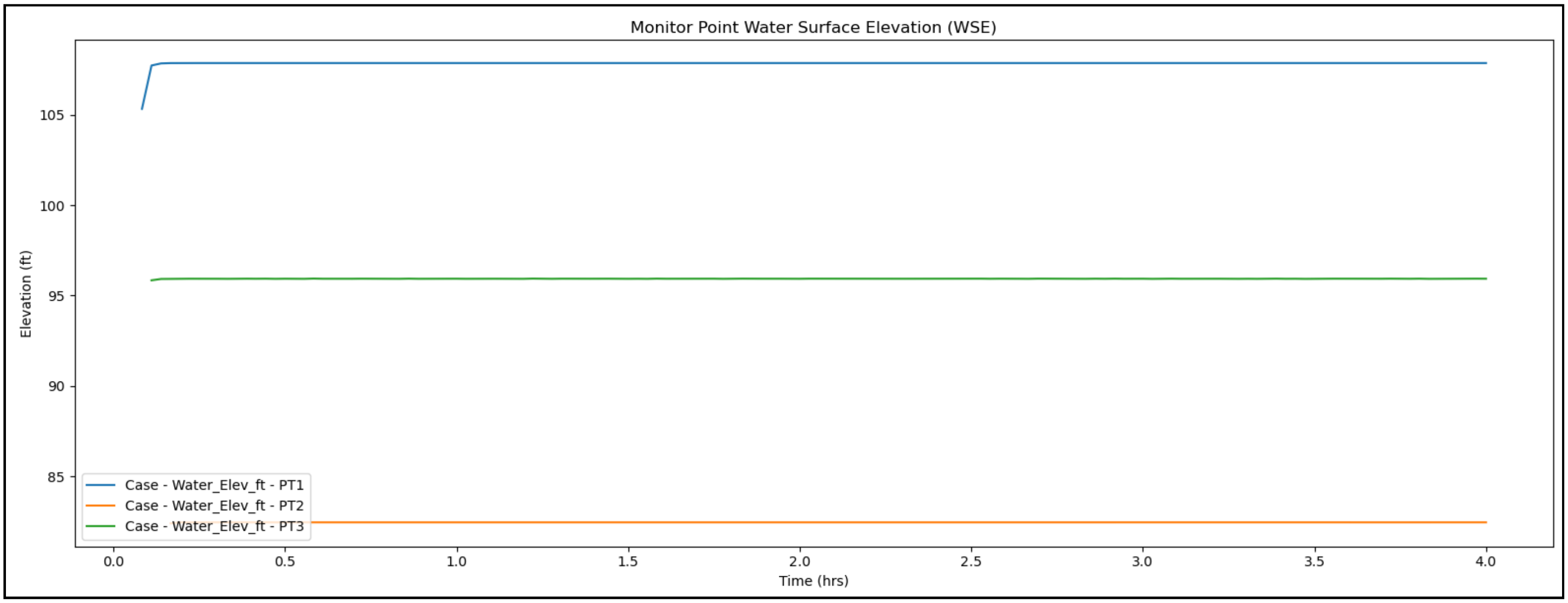
Appendix I: SRH-2D Model Stability and Continuity

Appendix I.1 - Existing Conditions Monitor Lines and Points

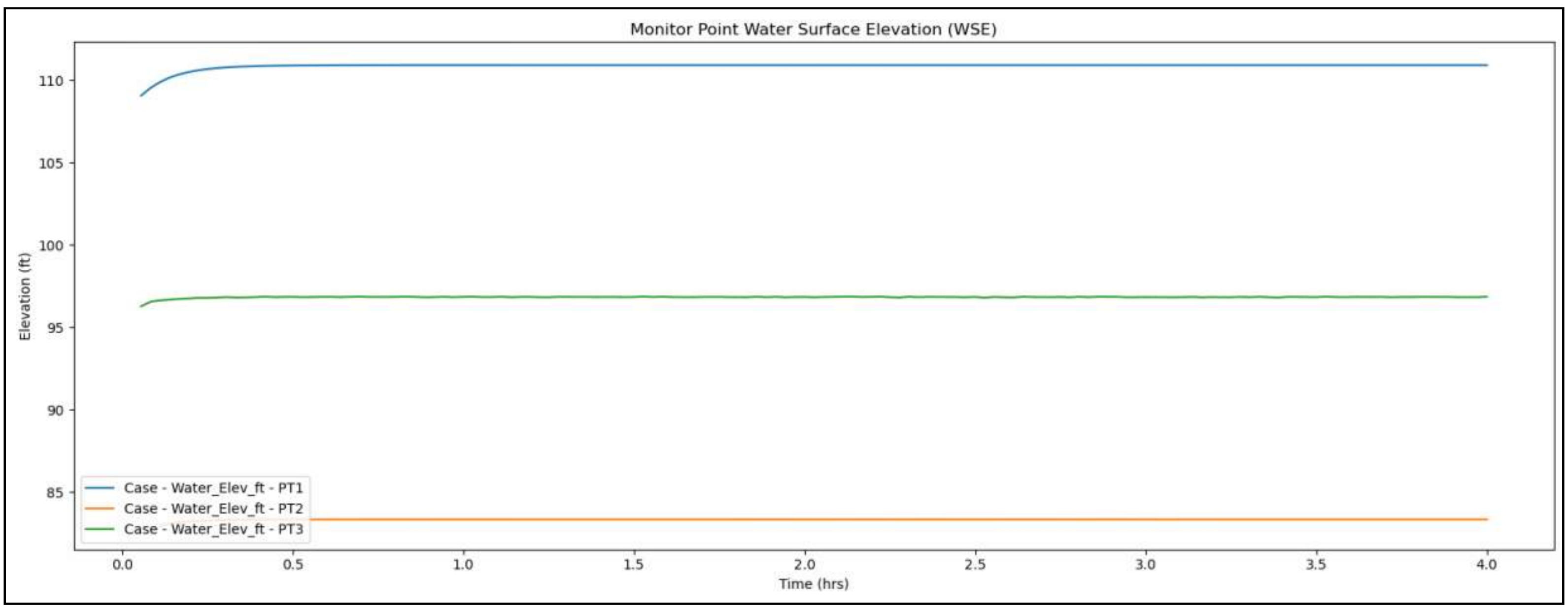


Little Scandia Creek (992008) Existing Monitor Point Results

2-Year Existing

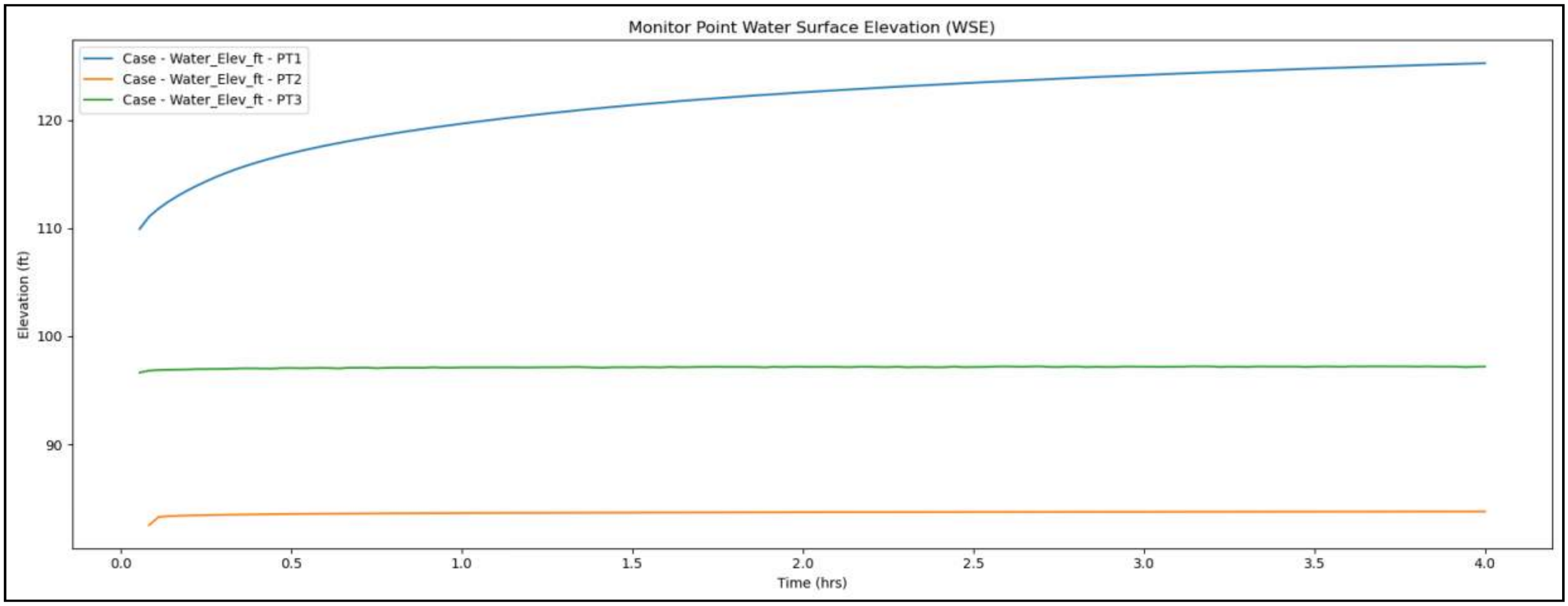


100-Year Existing



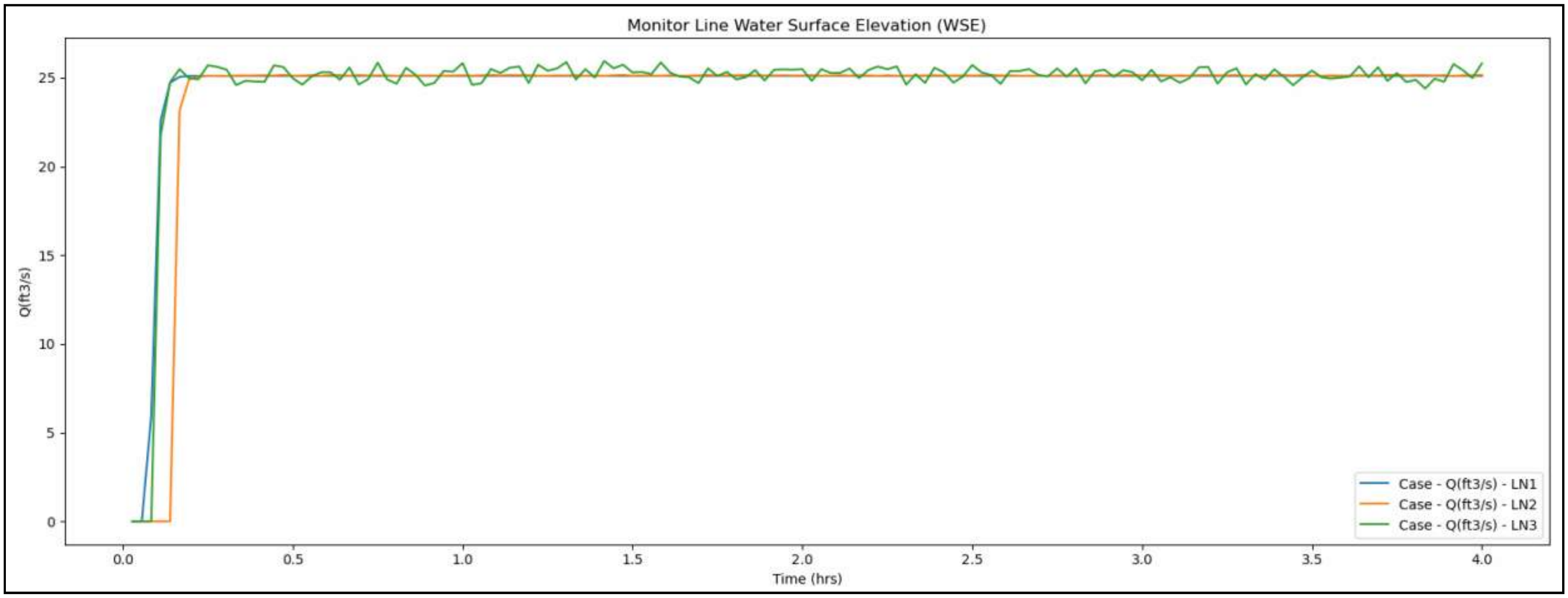
Little Scandia Creek (992008) Existing Monitor Point Results

500-Year Existing

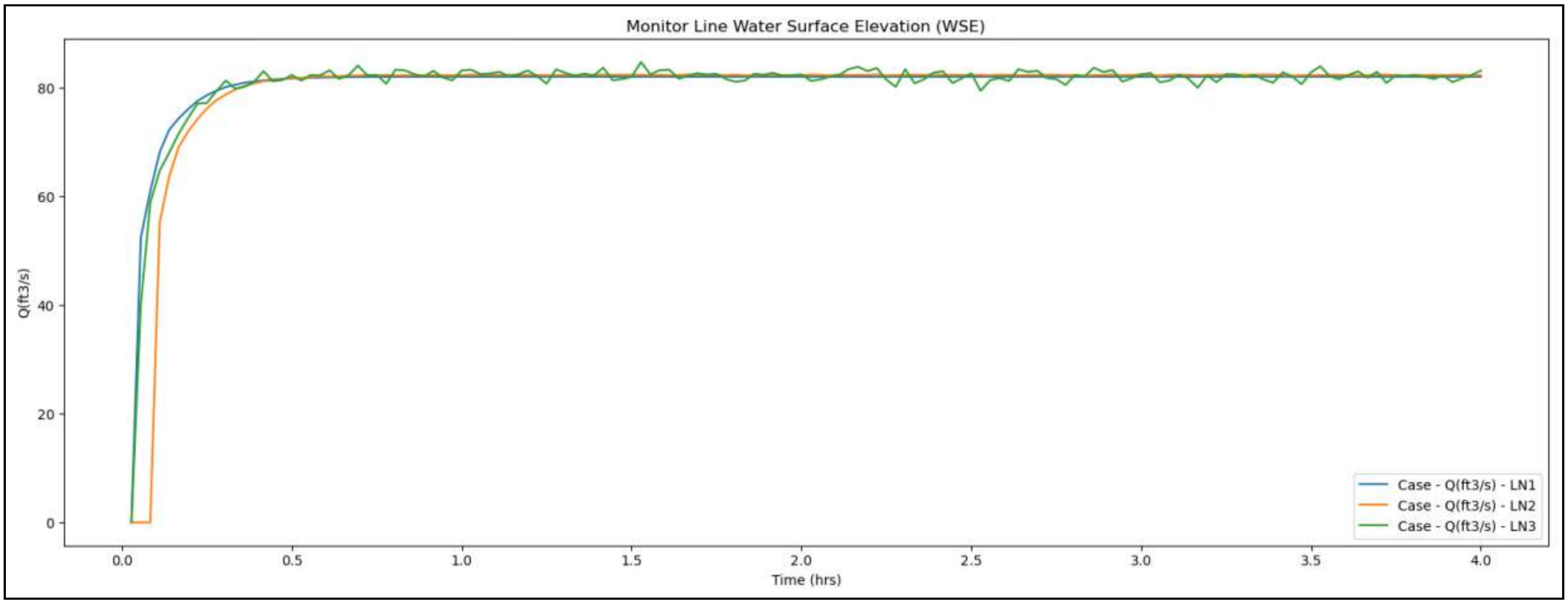


Little Scandia Creek (992008) Existing Monitor Line Results

2-Year Existing

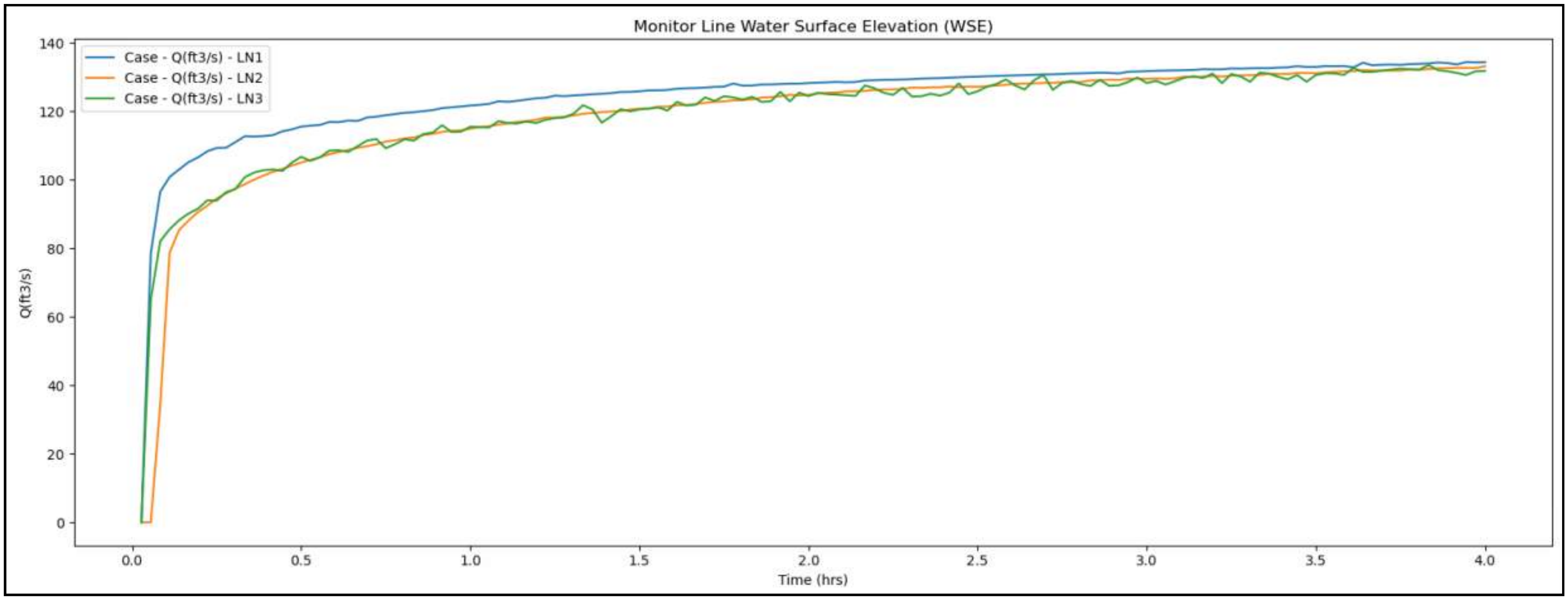


100-Year Existing

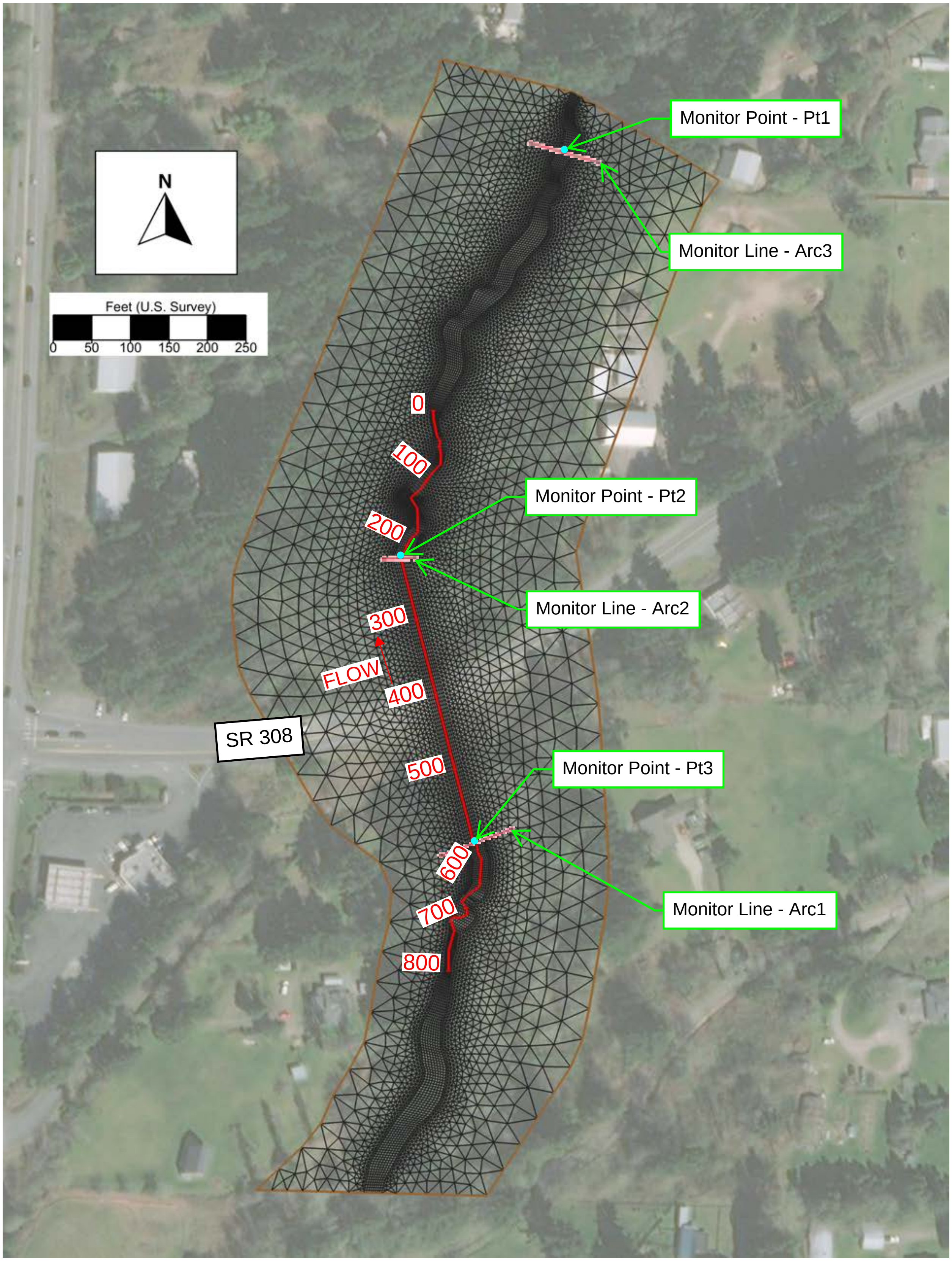


Little Scandia Creek (992008) Existing Monitor Line Results

500-Year Existing

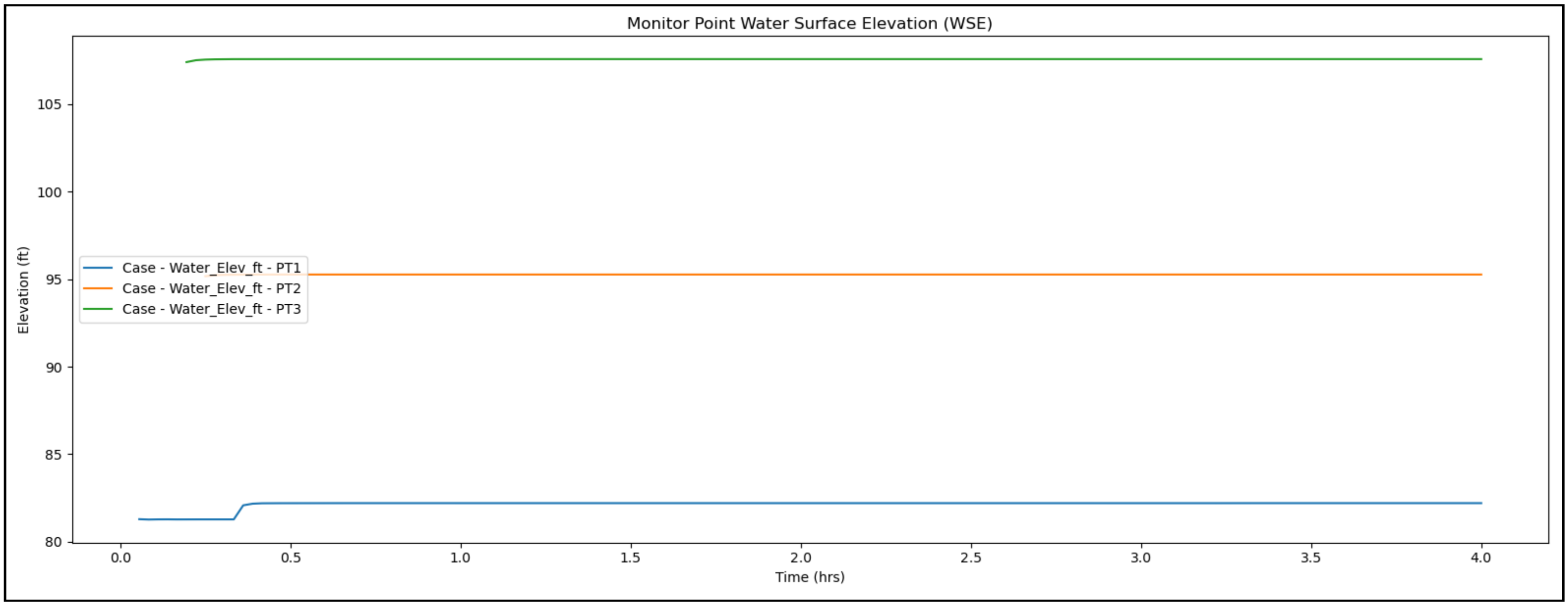


Appendix I.2 - Proposed Conditions Monitor Lines and Points

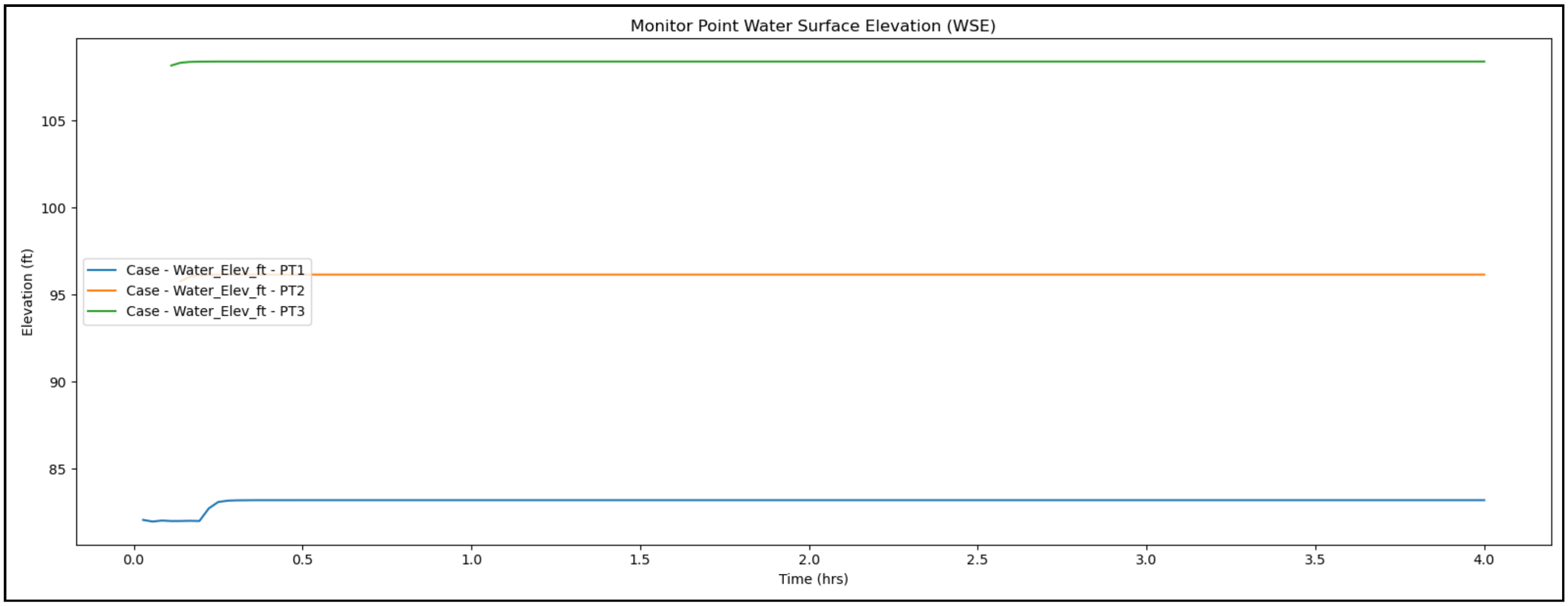


Little Scandia Creek (992008) Proposed Monitor Point Results

2-Year Proposed

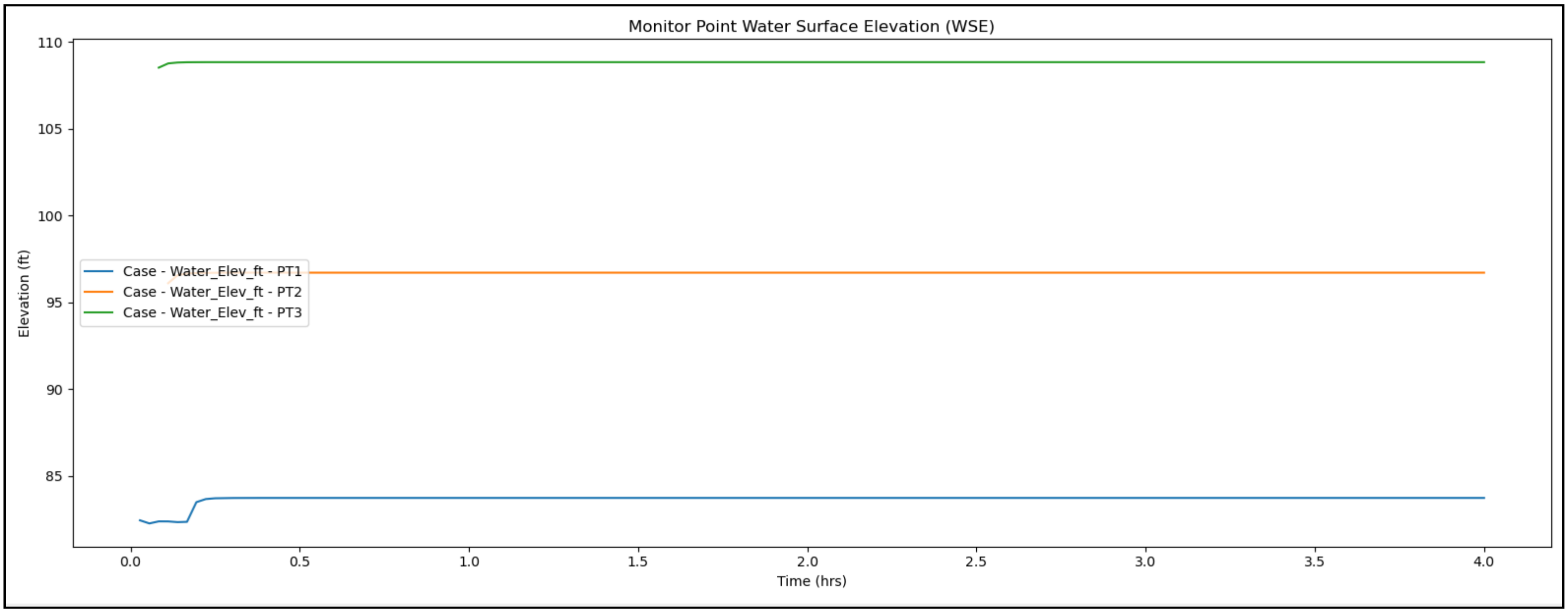


100-Year Proposed

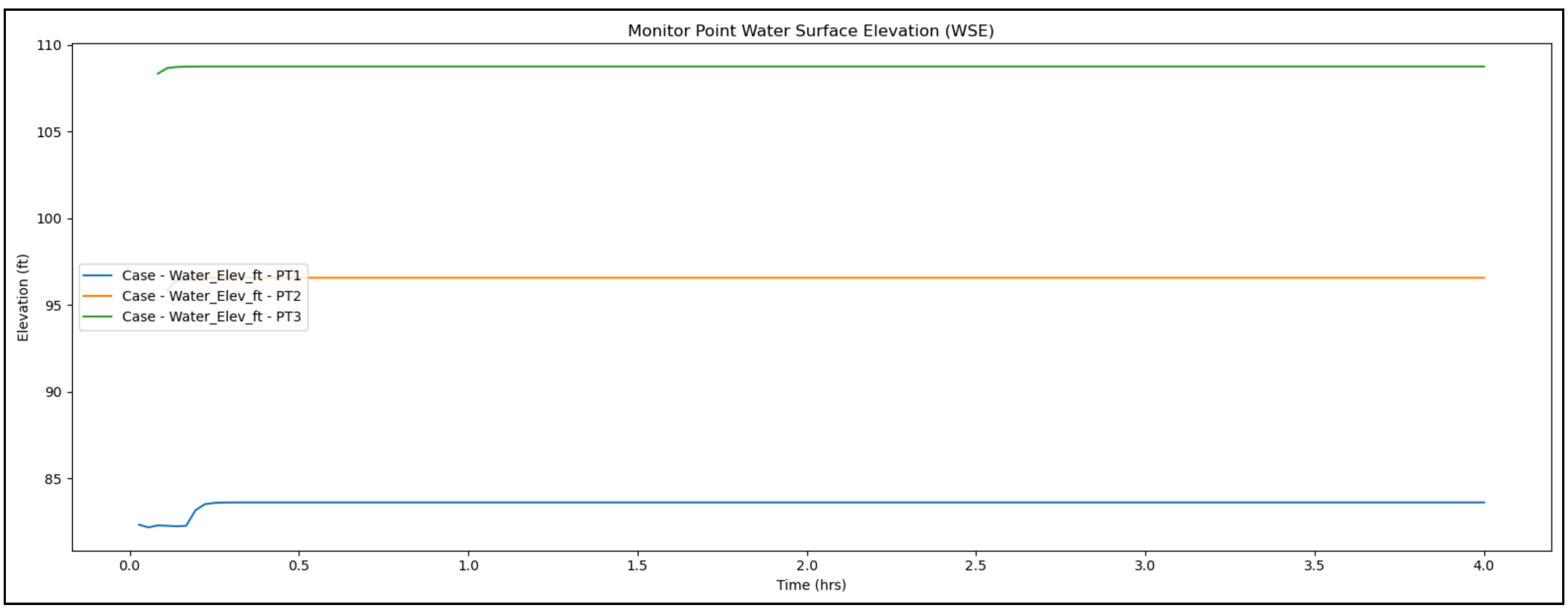


Little Scandia Creek (992008) Proposed Monitor Point Results

500-Year Proposed

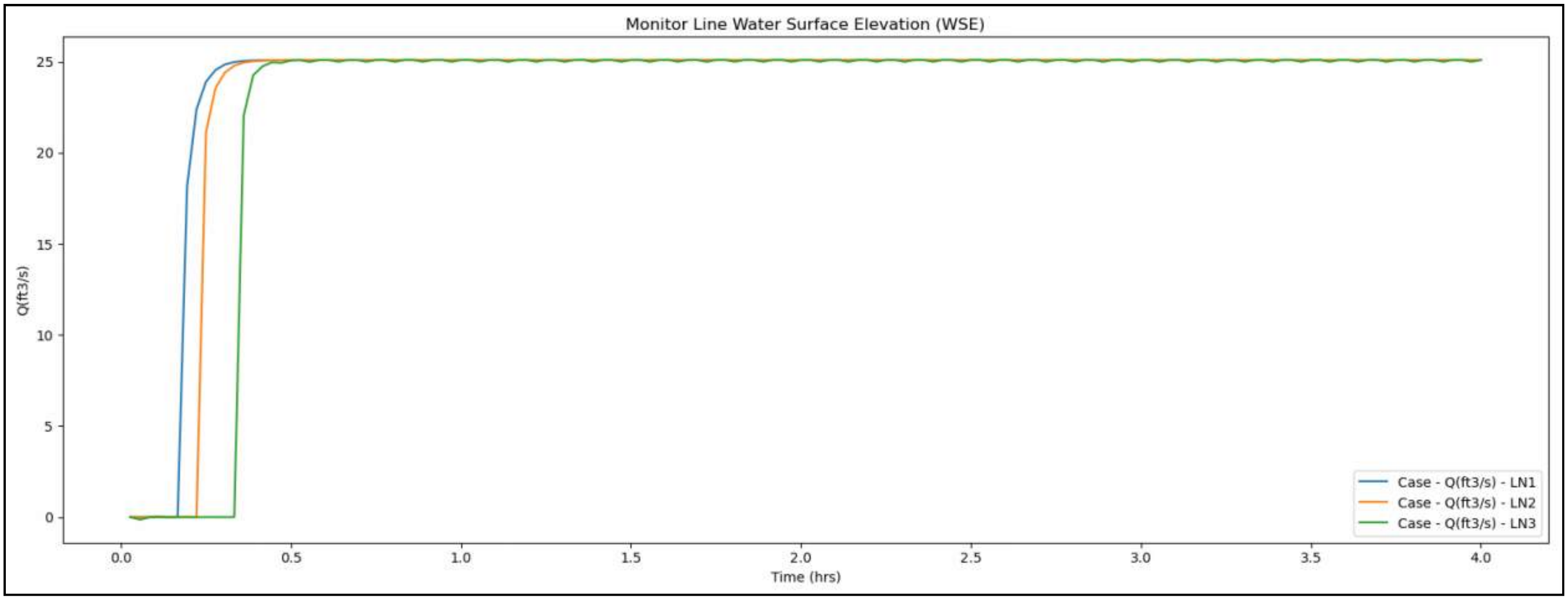


2080 100-Year Proposed

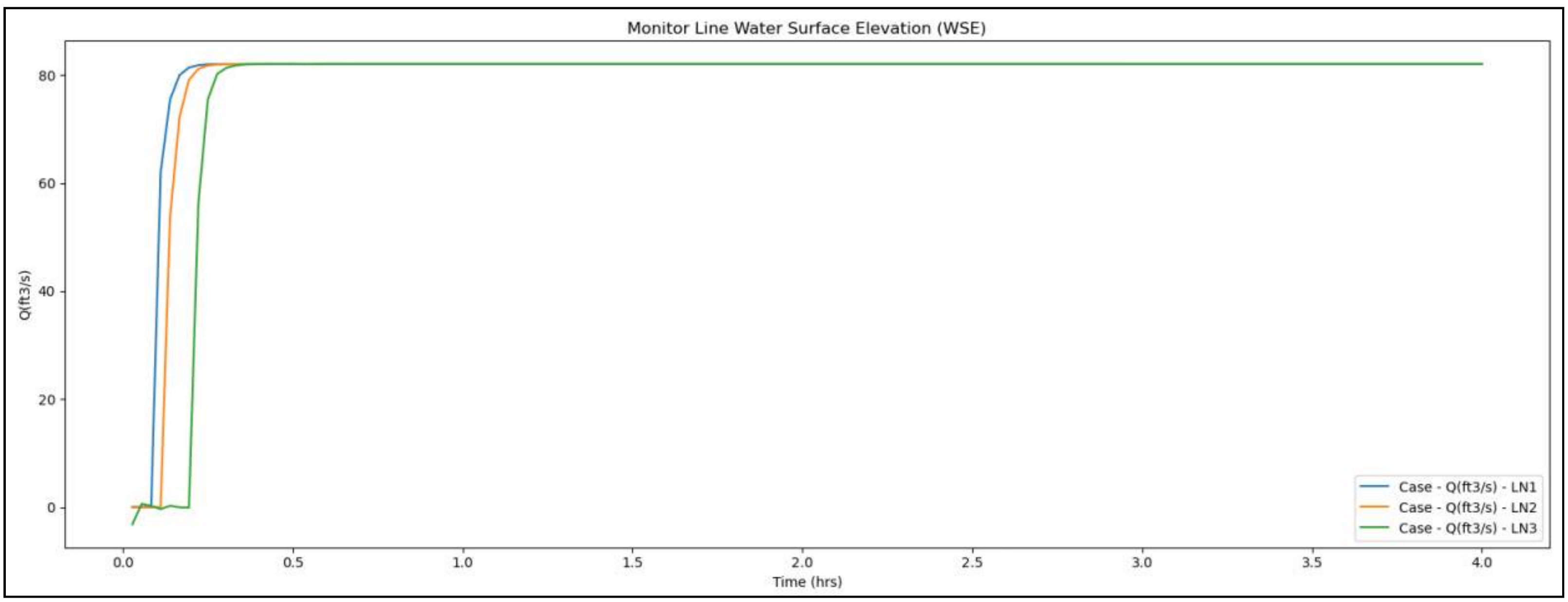


Little Scandia Creek (992008) Proposed Monitor Line Results

2-Year Proposed

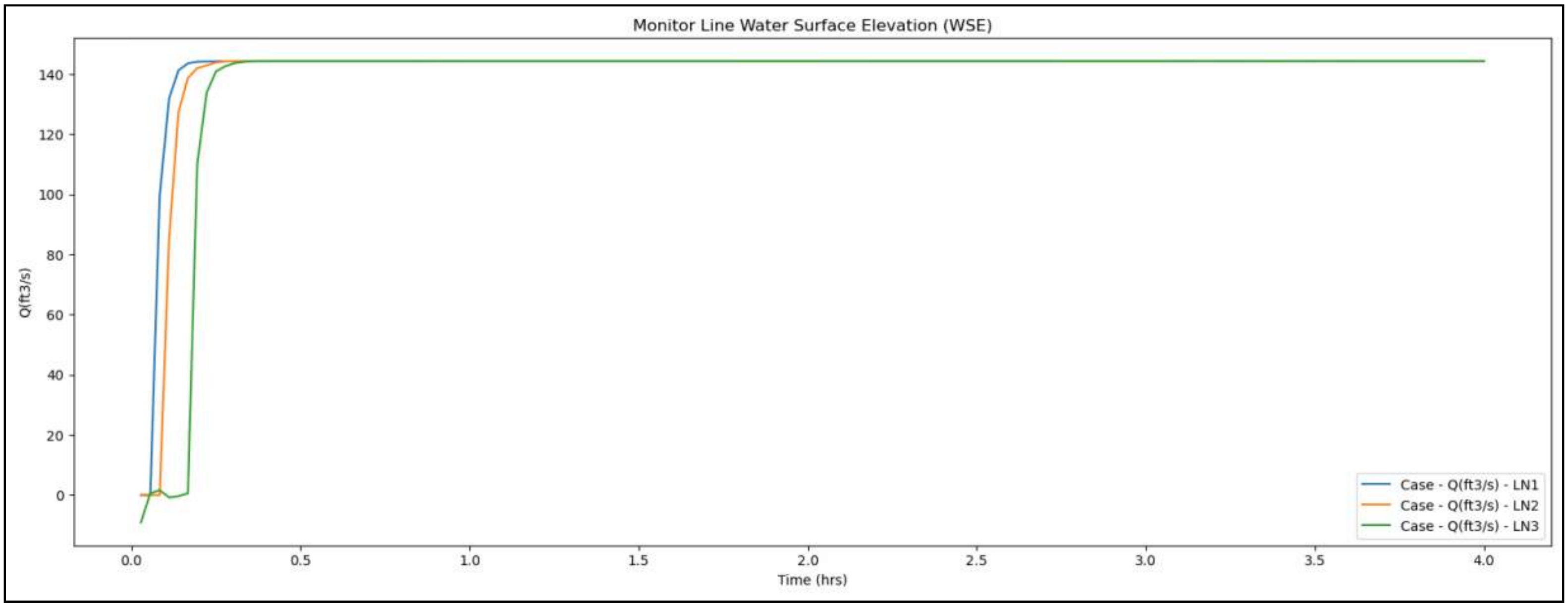


100-Year Proposed

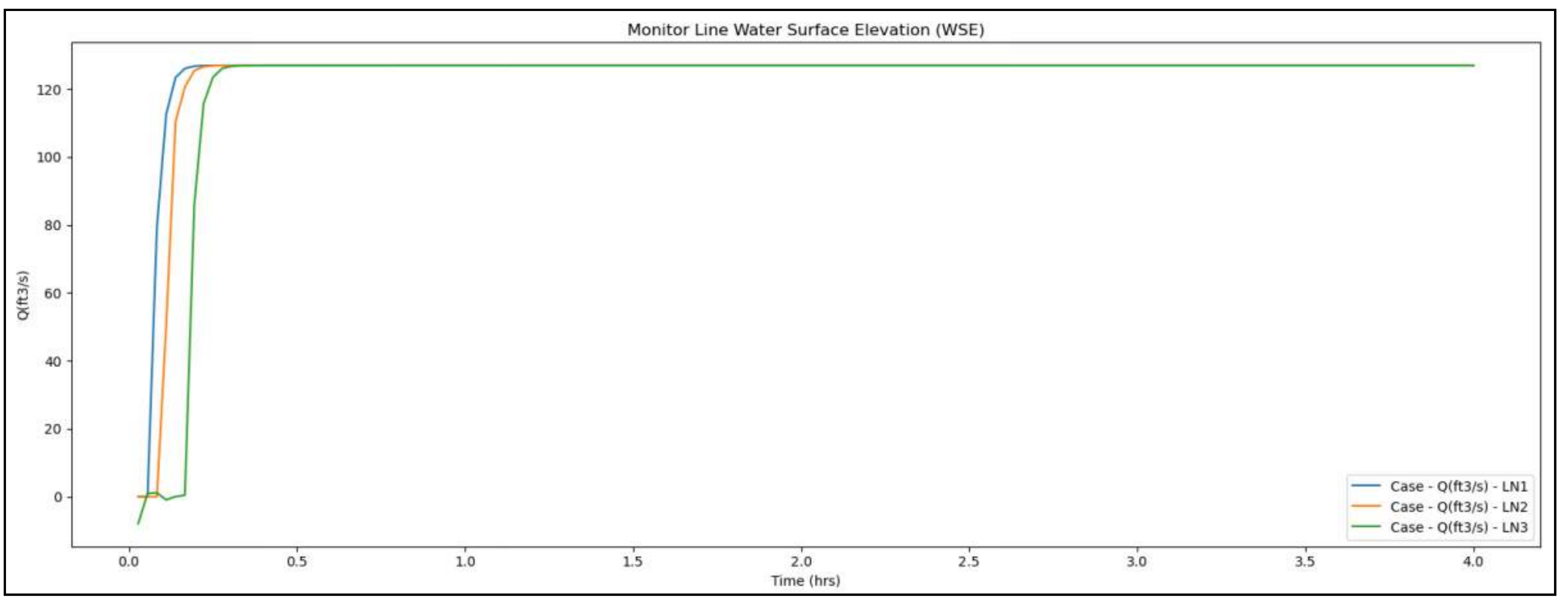


Little Scandia Creek (992008) Proposed Monitor Line Results

500-Year Proposed



2080 100-Year Proposed



Appendix J: Reach Assessment

(Not used)

Appendix K: Scour Calculations

(Preliminary)

SMS Bridge Scour Coverage Figures

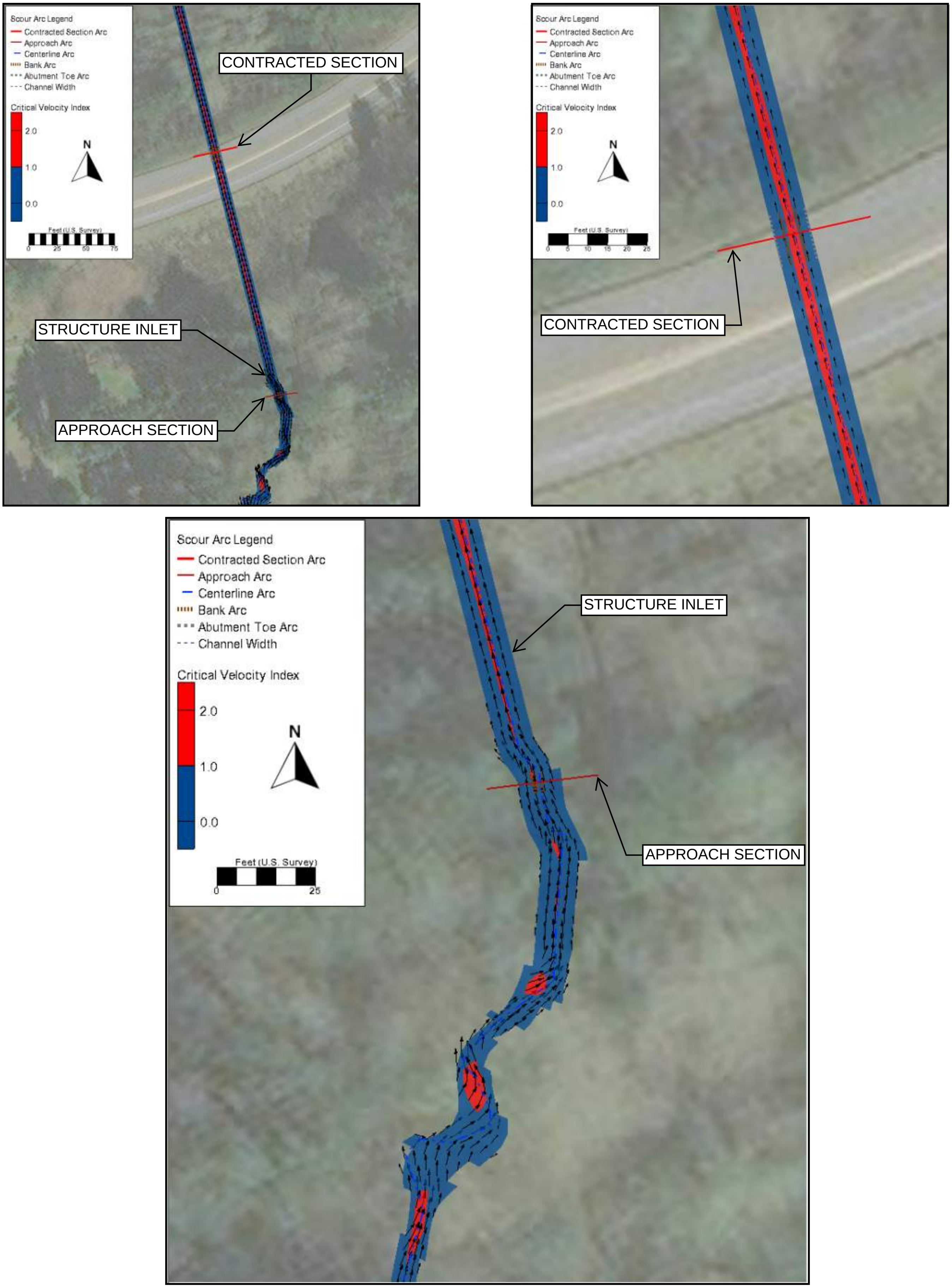


Figure K-1: Scour coverage and velocity vectors for the 2-year event.

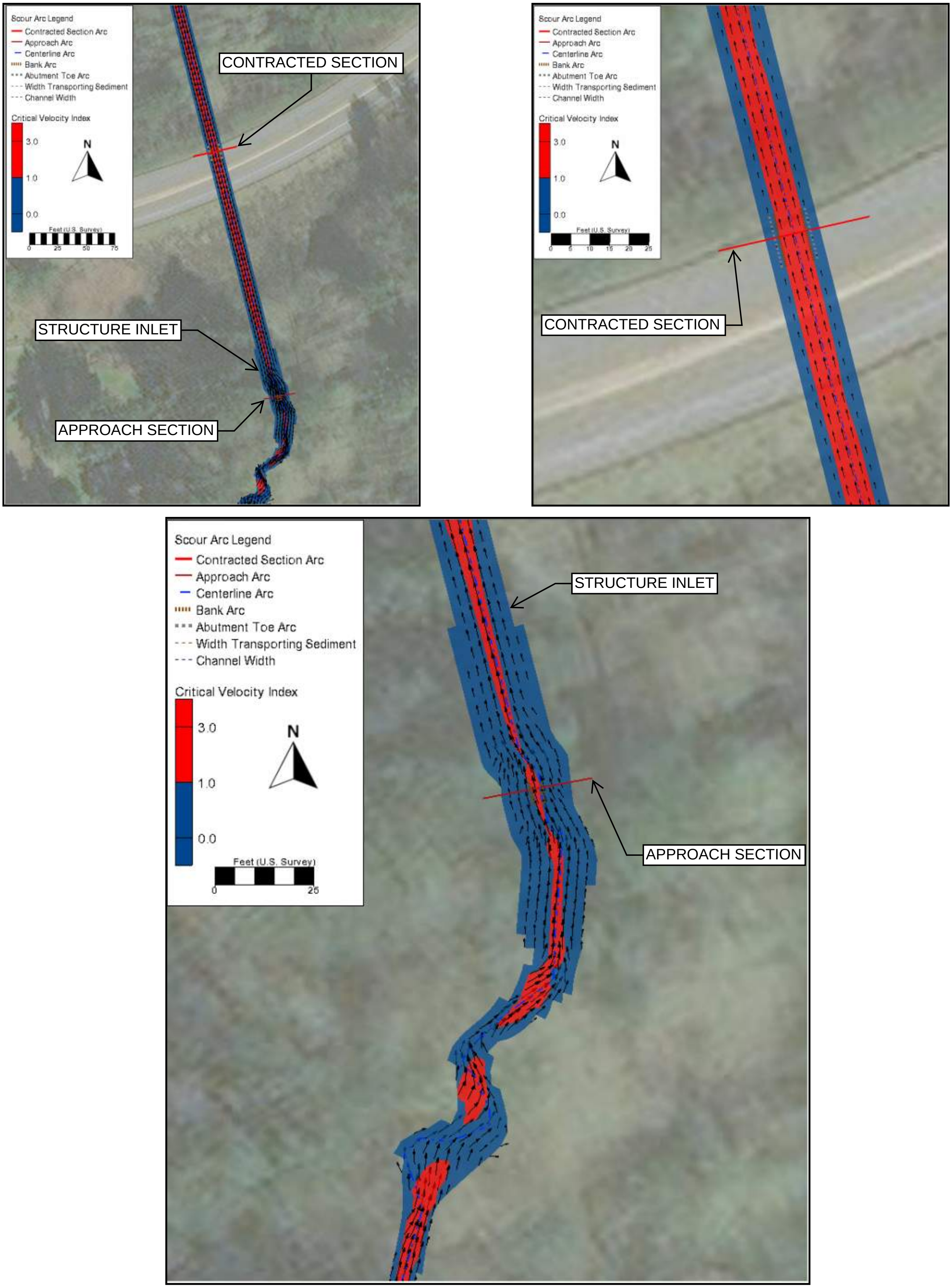


Figure K-2: Scour coverage and velocity vectors for the 10-year event.

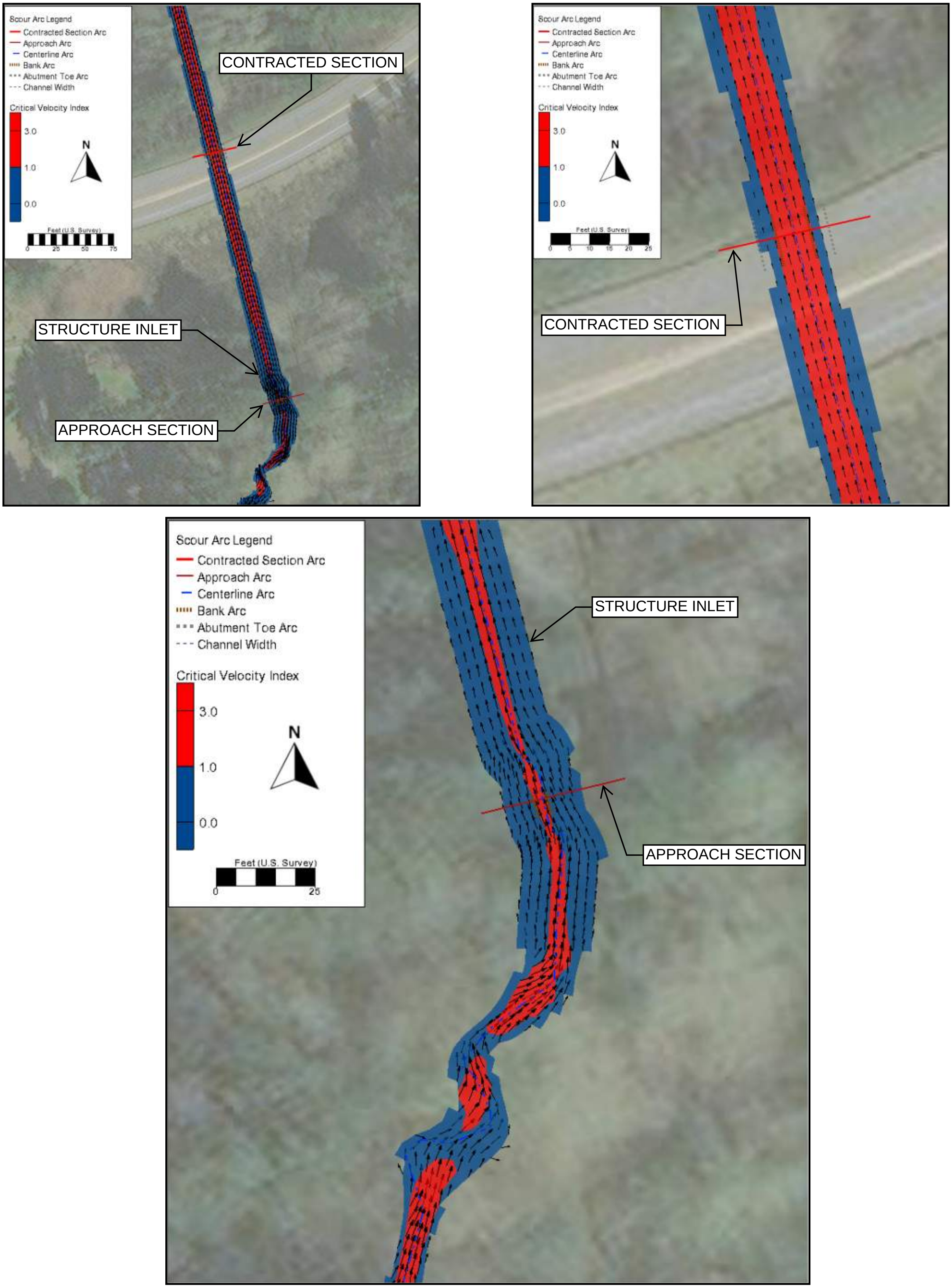


Figure K-3: Scour coverage and velocity vectors for the 50-year event.

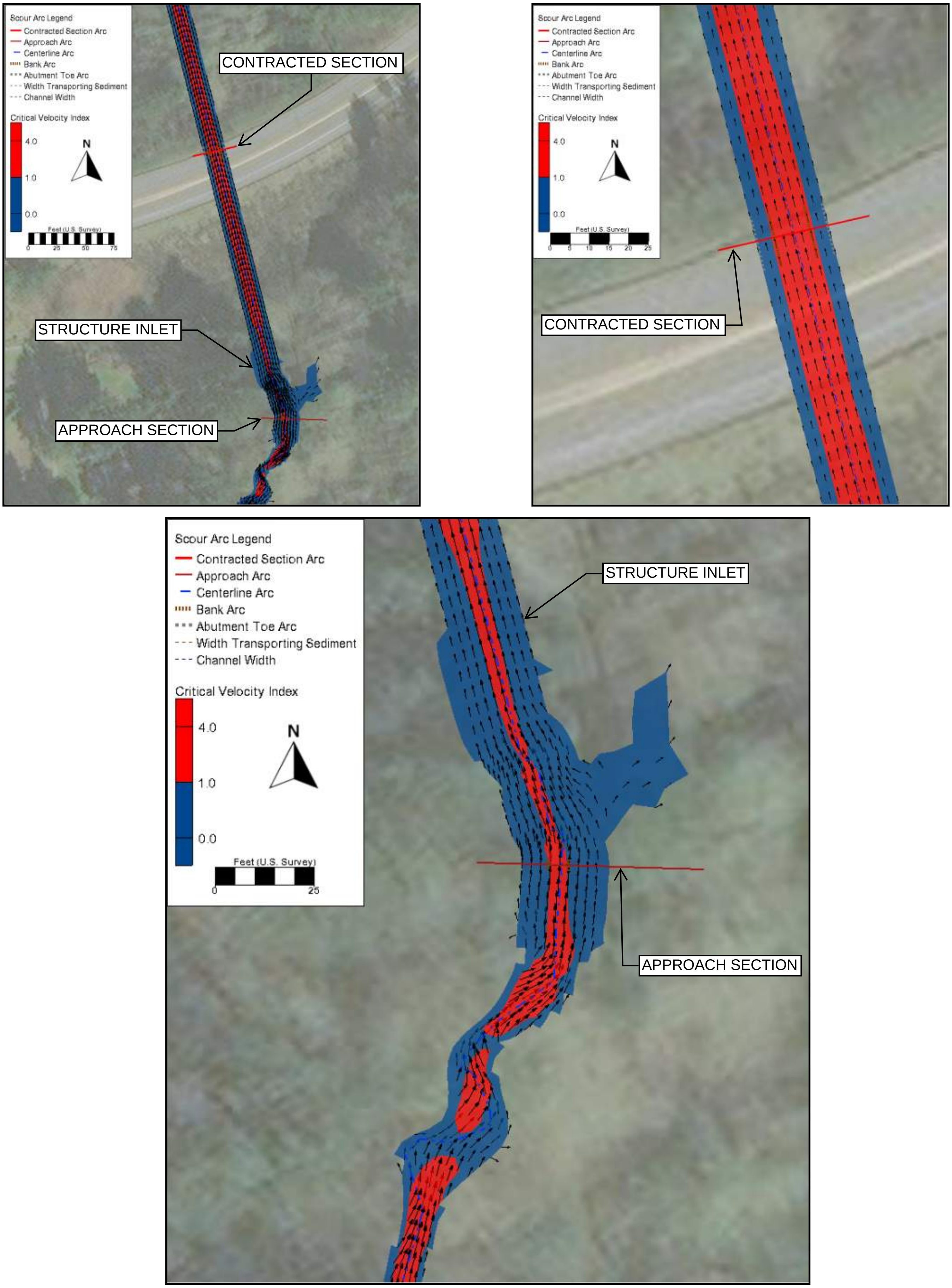


Figure K-4: Scour coverage and velocity vectors for the 100-year event.

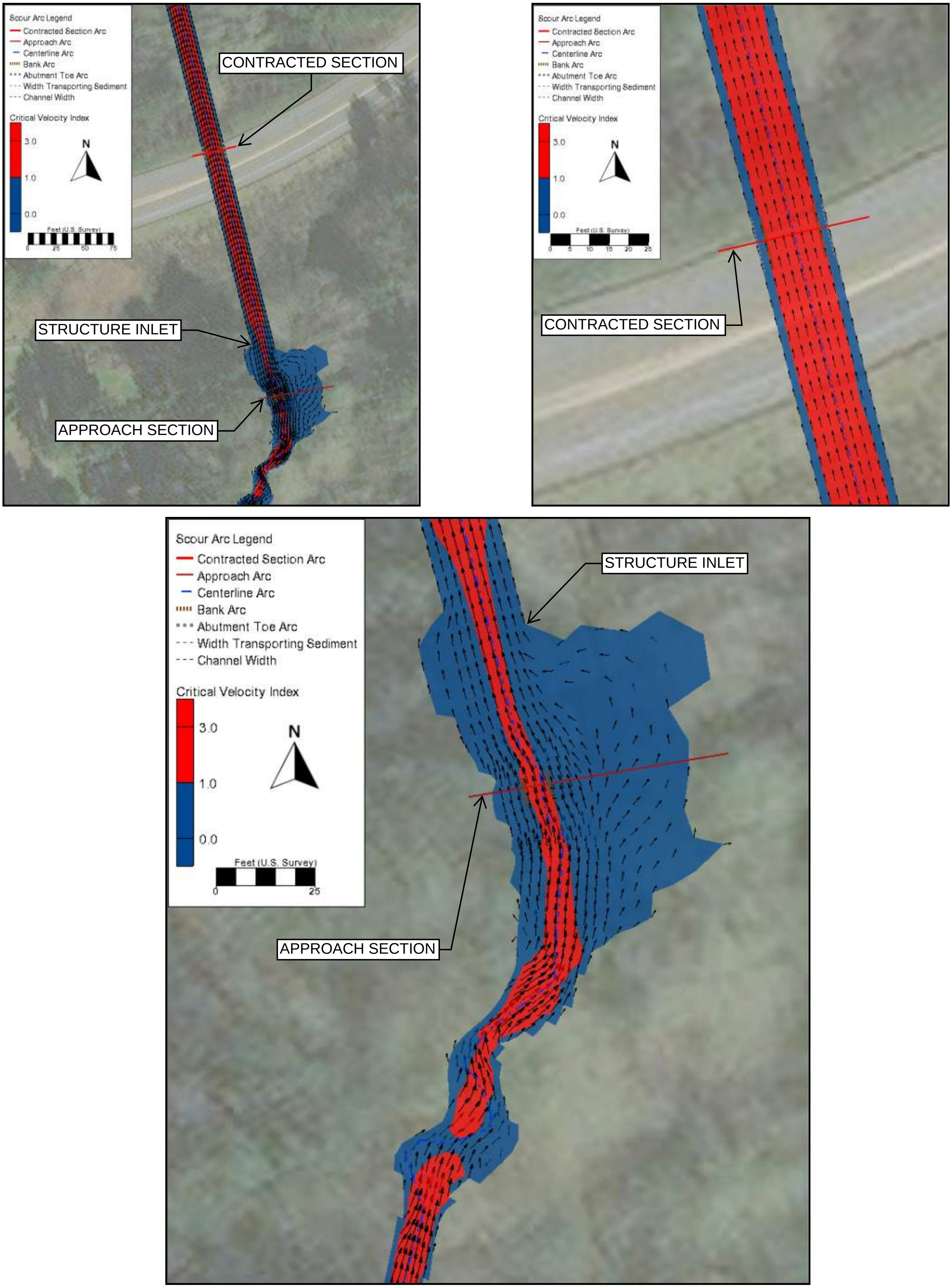


Figure K-5: Scour coverage and velocity vectors for the 2080 100-year event.

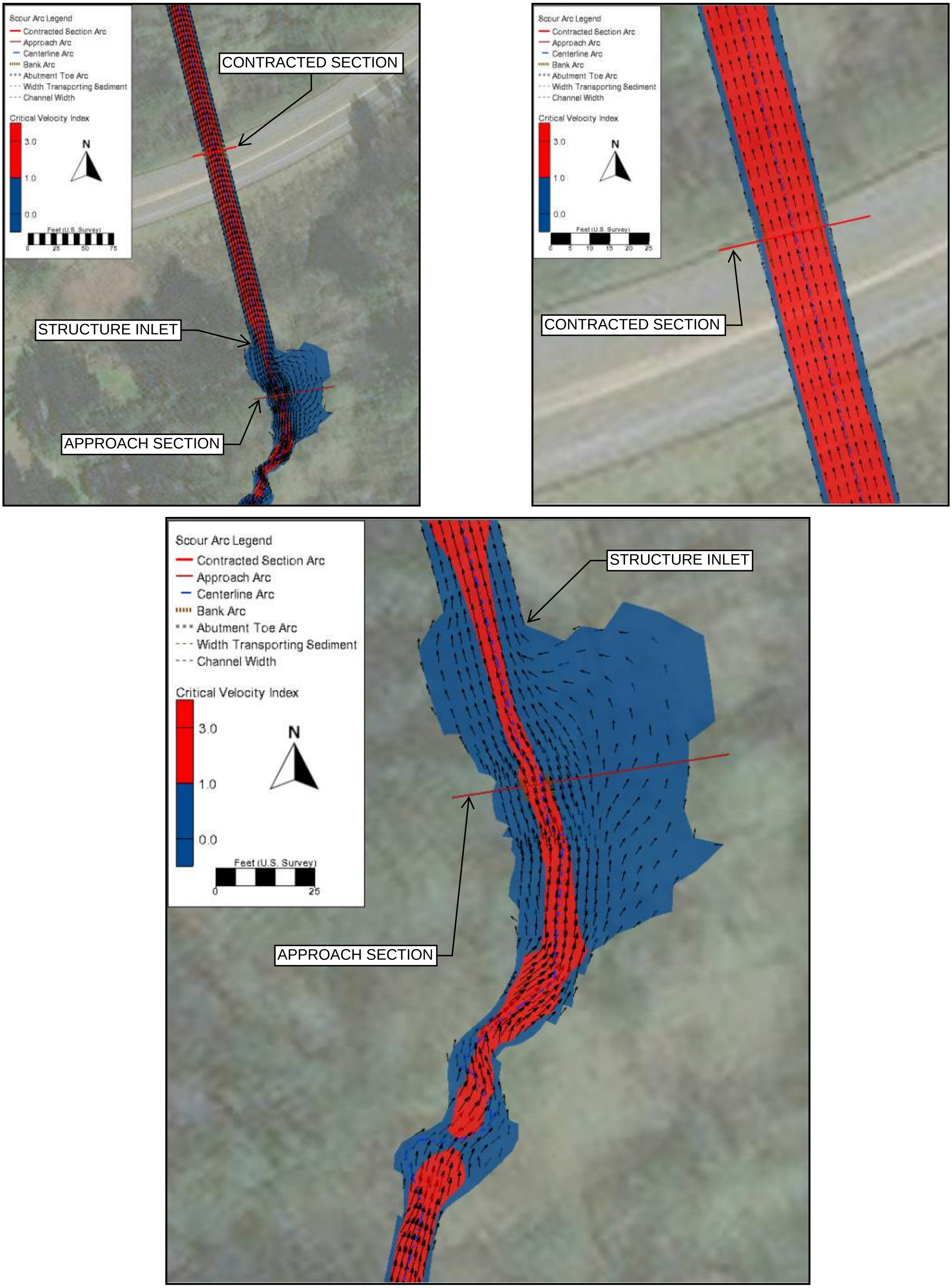


Figure K-6: Scour coverage and velocity vectors for the 500-year event.

Hydraulic Toolbox Model Output

Hydraulic Analysis Report

Project Data

Project Title:

Designer:

Project Date: Friday, October 14, 2022

Project Units: U.S. Customary Units

Notes:

Bridge Scour Analysis:992008 2 yr Bridge Scour Analysis

Notes:

Scenario: 2yr_Proposed-6 (SRH-2D)

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Live Bed Contraction Scour Depth 0.20 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.08 ft

Total Scour at Abutment 0.08 ft

Right Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.08 ft

Total Scour at Abutment 0.08 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.04 ft

D50: 20.421600 mm

Average Velocity Upstream: 4.43 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 4.56 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 17.02 cfs

Bottom Width in Contracted Section: 4.11 ft

Depth Prior to Scour in Contracted Section: 0.90 ft

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0341 ft/ft

Flow in Contracted Section: 17.02 cfs

Flow Upstream that is Transporting Sediment: 9.46 cfs

Width in Contracted Section: 4.11 ft

Width Upstream that is Transporting Sediment: 2.06 ft

Depth Prior to Scour in Contracted Section: 0.90 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 25.527000 mm

Average Depth in Contracted Section after Scour: 0.85 ft

Scour Depth: -0.05 ft

Results of Live Bed Method

Shear Velocity: 1.07 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 1.10 ft

Scour Depth for Live Bed: 0.20 ft

Shear Applied to Bed by Live-Bed Scour: 0.1935 lb/ft^2

Shear Required for Movement of D50 Particle: 0.2681 lb/ft^2

Recommendations

Recommended Scour Depth: -0.05 ft

Left Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.49 ft

D50: 0.000000 mm

Average Velocity Upstream: 1.26 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0341 ft/ft

Flow in Contracted Section: 2.99 cfs

Flow Upstream that is Transporting Sediment: 2.28 cfs

Width in Contracted Section: 2.69 ft

Width Upstream that is Transporting Sediment: 3.68 ft

Depth Prior to Scour in Contracted Section: 0.37 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Right Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.75 ft

D50: 0.000000 mm

Average Velocity Upstream: 2.35 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0341 ft/ft

Flow in Contracted Section: 8.46 cfs

Flow Upstream that is Transporting Sediment: 9.50 cfs

Width in Contracted Section: 2.71 ft

Width Upstream that is Transporting Sediment: 5.34 ft

Depth Prior to Scour in Contracted Section: 1.06 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 91.15 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 4.60 cfs

Unit Discharge in the Constricted Area (q2): 4.14 cfs/ft

D50: 20.421600 mm

Upstream Flow Depth: 1.04 ft

Flow Depth Prior to Scour: 1.03 ft

Result Parameters

q2/q1: 0.90

Average Velocity Upstream: 4.43 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 4.56 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 0.92 ft

Maximum Flow Depth including Abutment Scour: 1.11 ft

Scour Hole Depth from NCHRP Method: 0.08 ft

Right Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 88.85 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 4.60 cfs

Unit Discharge in the Constricted Area (q2): 4.14 cfs/ft

D50: 20.421600 mm

Upstream Flow Depth: 1.04 ft

Flow Depth Prior to Scour: 1.03 ft

Result Parameters

q2/q1: 0.90

Average Velocity Upstream: 4.43 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 4.56 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 0.92 ft

Maximum Flow Depth including Abutment Scour: 1.11 ft

Scour Hole Depth from NCHRP Method: 0.08 ft

Hydraulic Analysis Report

Project Data

Project Title:

Designer:

Project Date: Friday, October 14, 2022

Project Units: U.S. Customary Units

Notes:

Bridge Scour Analysis:992008 10 yr Bridge Scour Analysis

Notes:

Scenario: 10yr_Proposed-6 (SRH-2D)

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Applied Contraction Scour Depth 0.07 ft

Contraction & Long Term Scour is applied method due to greater scour.

Pressure Scour Depth 0.07 ft

Clear Water Contraction Scour Depth 0.07 ft

Live Bed Contraction Scour Depth 0.42 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.10 ft

Total Scour at Abutment 0.00 ft

Right Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.10 ft

Total Scour at Abutment 0.00 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.42 ft

D50: 20.421600 mm

Average Velocity Upstream: 4.91 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 4.81 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0337 ft/ft

Flow in Contracted Section: 41.77 cfs

Flow Upstream that is Transporting Sediment: 19.40 cfs

Width in Contracted Section: 7.11 ft

Width Upstream that is Transporting Sediment: 2.78 ft

Depth Prior to Scour in Contracted Section: 1.08 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 25.527000 mm

Average Depth in Contracted Section after Scour: 1.15 ft

Scour Depth: 0.07 ft

Results of Live Bed Method

Shear Velocity: 1.24 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 1.50 ft

Scour Depth for Live Bed: 0.42 ft

Shear Applied to Bed by Live-Bed Scour: 0.2324 lb/ft^2

Shear Required for Movement of D50 Particle: 0.2681 lb/ft^2

Scour is limited by armoring. Use Clear-Water estimate.

Recommendations

Recommended Scour Depth: 0.07 ft

Left Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.48 ft

D50: 0.000000 mm

Average Velocity Upstream: 2.58 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0337 ft/ft

Flow in Contracted Section: 0.70 cfs

Flow Upstream that is Transporting Sediment: 9.22 cfs

Width in Contracted Section: 3.63 ft

Width Upstream that is Transporting Sediment: 7.47 ft

Depth Prior to Scour in Contracted Section: 0.22 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Right Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.91 ft

D50: 0.000000 mm

Average Velocity Upstream: 2.94 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0337 ft/ft

Flow in Contracted Section: 4.68 cfs

Flow Upstream that is Transporting Sediment: 20.33 cfs

Width in Contracted Section: 3.53 ft

Width Upstream that is Transporting Sediment: 7.59 ft

Depth Prior to Scour in Contracted Section: 0.50 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 91.22 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 6.97 cfs

Unit Discharge in the Constricted Area (q2): 5.87 cfs/ft

D50: 20.421600 mm

Upstream Flow Depth: 1.42 ft

Flow Depth Prior to Scour: 1.35 ft

Result Parameters

q2/q1: 0.84

Average Velocity Upstream: 4.91 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 4.81 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.25 ft

Maximum Flow Depth including Abutment Scour: 1.25 ft

Scour Hole Depth from NCHRP Method: -0.10 ft

Right Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 88.78 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 6.97 cfs

Unit Discharge in the Constricted Area (q2): 5.87 cfs/ft

D50: 20.421600 mm

Upstream Flow Depth: 1.42 ft

Flow Depth Prior to Scour: 1.35 ft

Result Parameters

q2/q1: 0.84

Average Velocity Upstream: 4.91 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 4.81 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.25 ft

Maximum Flow Depth including Abutment Scour: 1.25 ft

Scour Hole Depth from NCHRP Method: -0.10 ft

Hydraulic Analysis Report

Project Data

Project Title:

Designer:

Project Date: Friday, October 14, 2022

Project Units: U.S. Customary Units

Notes:

Bridge Scour Analysis:992008 50 yr Bridge Scour Analysis

Notes:

Scenario: 50yr_Proposed-6 (SRH-2D)

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Applied Contraction Scour Depth 0.16 ft

Contraction & Long Term Scour is applied method due to greater scour.

Pressure Scour Depth 0.16 ft

Clear Water Contraction Scour Depth 0.16 ft

Live Bed Contraction Scour Depth 0.53 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.09 ft

Total Scour at Abutment 0.00 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.65 ft

D50: 20.421600 mm

Average Velocity Upstream: 5.09 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 4.93 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0342 ft/ft

Flow in Contracted Section: 58.38 cfs

Flow Upstream that is Transporting Sediment: 29.51 cfs

Width in Contracted Section: 8.49 ft

Width Upstream that is Transporting Sediment: 3.51 ft

Depth Prior to Scour in Contracted Section: 1.16 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 25.527000 mm

Average Depth in Contracted Section after Scour: 1.32 ft

Scour Depth: 0.16 ft

Results of Live Bed Method

Shear Velocity: 1.35 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 1.68 ft

Scour Depth for Live Bed: 0.53 ft

Shear Applied to Bed by Live-Bed Scour: 0.2631 lb/ft^2

Shear Required for Movement of D50 Particle: 0.2681 lb/ft^2

Scour is limited by armoring. Use Clear-Water estimate.

Recommendations

Recommended Scour Depth: 0.16 ft

Left Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.71 ft

D50: 0.000000 mm

Average Velocity Upstream: 2.50 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0342 ft/ft

Flow in Contracted Section: 2.50 cfs

Flow Upstream that is Transporting Sediment: 13.41 cfs

Width in Contracted Section: 5.31 ft

Width Upstream that is Transporting Sediment: 7.60 ft

Depth Prior to Scour in Contracted Section: 0.18 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Right Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.59 ft

D50: 0.000000 mm

Average Velocity Upstream: 2.66 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0342 ft/ft

Flow in Contracted Section: 8.56 cfs

Flow Upstream that is Transporting Sediment: 14.16 cfs

Width in Contracted Section: 2.83 ft

Width Upstream that is Transporting Sediment: 8.98 ft

Depth Prior to Scour in Contracted Section: 0.90 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 91.25 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 8.40 cfs

Unit Discharge in the Constricted Area (q2): 6.88 cfs/ft

D50: 20.421600 mm

Upstream Flow Depth: 1.65 ft

Flow Depth Prior to Scour: 1.52 ft

Result Parameters

q2/q1: 0.82

Average Velocity Upstream: 5.09 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 4.93 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.43 ft

Maximum Flow Depth including Abutment Scour: 1.43 ft

Scour Hole Depth from NCHRP Method: -0.09 ft

Hydraulic Analysis Report

Project Data

Project Title:

Designer:

Project Date: Friday, October 14, 2022

Project Units: U.S. Customary Units

Notes:

Bridge Scour Analysis:992008 100 yr Bridge Scour Analysis

Notes:

Scenario: 100yr_Proposed-6 (SRH-2D)

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Applied Contraction Scour Depth 0.23 ft

Contraction & Long Term Scour is applied method due to greater scour.

Pressure Scour Depth 0.23 ft

Clear Water Contraction Scour Depth 0.23 ft

Live Bed Contraction Scour Depth 0.45 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.06 ft

Total Scour at Abutment 0.00 ft

Right Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.06 ft

Total Scour at Abutment 0.00 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.74 ft

D50: 20.421600 mm

Average Velocity Upstream: 5.41 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 4.98 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0335 ft/ft

Flow in Contracted Section: 73.01 cfs

Flow Upstream that is Transporting Sediment: 48.88 cfs

Width in Contracted Section: 9.39 ft

Width Upstream that is Transporting Sediment: 5.19 ft

Depth Prior to Scour in Contracted Section: 1.23 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 25.527000 mm

Average Depth in Contracted Section after Scour: 1.46 ft

Scour Depth: 0.23 ft

Results of Live Bed Method

Shear Velocity: 1.37 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 1.68 ft

Scour Depth for Live Bed: 0.45 ft

Shear Applied to Bed by Live-Bed Scour: 0.3381 lb/ft^2

Shear Required for Movement of D50 Particle: 0.2681 lb/ft^2

Recommendations

Recommended Scour Depth: 0.23 ft

Left Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.69 ft

D50: 0.000000 mm

Average Velocity Upstream: 1.79 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0335 ft/ft

Flow in Contracted Section: 5.08 cfs

Flow Upstream that is Transporting Sediment: 7.85 cfs

Width in Contracted Section: 4.79 ft

Width Upstream that is Transporting Sediment: 6.37 ft

Depth Prior to Scour in Contracted Section: 0.27 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Right Bank Contraction Scour
Computation Type: Clear-Water or Live-Bed Scour

Input Parameters
Average Depth Upstream of Contraction: 1.03 ft

D50: 0.000000 mm

Average Velocity Upstream: 2.95 ft/s

Results of Scour Condition
Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0335 ft/ft

Flow in Contracted Section: 13.00 cfs

Flow Upstream that is Transporting Sediment: 31.52 cfs

Width in Contracted Section: 4.82 ft

Width Upstream that is Transporting Sediment: 10.36 ft

Depth Prior to Scour in Contracted Section: 0.72 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Left Abutment Details

Abutment Scour
Computation Type: NCHRP

Input Parameters

NCHRP Method
Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 91.26 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 9.42 cfs

Unit Discharge in the Constricted Area (q2): 7.77 cfs/ft

D50: 20.421600 mm

Upstream Flow Depth: 1.74 ft

Flow Depth Prior to Scour: 1.65 ft

Result Parameters
q2/q1: 0.83

Average Velocity Upstream: 5.41 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 4.98 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.59 ft

Maximum Flow Depth including Abutment Scour: 1.59 ft

Scour Hole Depth from NCHRP Method: -0.06 ft

Right Abutment Details

Abutment Scour
Computation Type: NCHRP

Input Parameters

NCHRP Method
Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 88.74 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 9.42 cfs

Unit Discharge in the Constricted Area (q2): 7.77 cfs/ft

D50: 20.421600 mm

Upstream Flow Depth: 1.74 ft

Flow Depth Prior to Scour: 1.65 ft

Result Parameters

q2/q1: 0.83

Average Velocity Upstream: 5.41 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 4.98 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.59 ft

Maximum Flow Depth including Abutment Scour: 1.59 ft

Scour Hole Depth from NCHRP Method: -0.06 ft

Hydraulic Analysis Report

Project Data

Project Title:

Designer:

Project Date: Friday, October 14, 2022

Project Units: U.S. Customary Units

Notes:

Bridge Scour Analysis:2080 100 yr Bridge Scour Analysis

Notes:

Scenario: 2080 100yr_Proposed-6 (SRH-2D)

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Applied Contraction Scour Depth 0.34 ft

Contraction & Long Term Scour is applied method due to greater scour.

Pressure Scour Depth 0.34 ft

Clear Water Contraction Scour Depth 0.34 ft

Live Bed Contraction Scour Depth 0.65 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.19 ft

Total Scour at Abutment 0.00 ft

Right Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.19 ft

Total Scour at Abutment 0.00 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.99 ft

D50: 20.421600 mm

Average Velocity Upstream: 5.44 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 5.09 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0335 ft/ft

Flow in Contracted Section: 117.91 cfs

Flow Upstream that is Transporting Sediment: 73.67 cfs

Width in Contracted Section: 13.56 ft

Width Upstream that is Transporting Sediment: 6.80 ft

Depth Prior to Scour in Contracted Section: 1.27 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 25.527000 mm

Average Depth in Contracted Section after Scour: 1.61 ft

Scour Depth: 0.34 ft

Results of Live Bed Method
Shear Velocity: 1.47 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 1.92 ft

Scour Depth for Live Bed: 0.65 ft

Shear Applied to Bed by Live-Bed Scour: 0.3387 lb/ft^2

Shear Required for Movement of D50 Particle: 0.2681 lb/ft^2

Recommendations

Recommended Scour Depth: 0.34 ft

Left Bank Contraction Scour
Computation Type: Clear-Water or Live-Bed Scour

Input Parameters
Average Depth Upstream of Contraction: 0.78 ft

D50: 0.000000 mm

Average Velocity Upstream: 2.64 ft/s

Results of Scour Condition
Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0335 ft/ft

Flow in Contracted Section: 4.06 cfs

Flow Upstream that is Transporting Sediment: 16.55 cfs

Width in Contracted Section: 2.74 ft

Width Upstream that is Transporting Sediment: 8.00 ft

Depth Prior to Scour in Contracted Section: 0.44 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Right Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.45 ft

D50: 0.000000 mm

Average Velocity Upstream: 2.50 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0335 ft/ft

Flow in Contracted Section: 9.33 cfs

Flow Upstream that is Transporting Sediment: 39.61 cfs

Width in Contracted Section: 2.70 ft

Width Upstream that is Transporting Sediment: 35.54 ft

Depth Prior to Scour in Contracted Section: 0.97 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 91.28 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 10.84 cfs

Unit Discharge in the Constricted Area (q2): 8.69 cfs/ft

D50: 20.421600 mm

Upstream Flow Depth: 1.99 ft

Flow Depth Prior to Scour: 1.94 ft

Result Parameters

q2/q1: 0.80

Average Velocity Upstream: 5.44 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 5.09 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.75 ft

Maximum Flow Depth including Abutment Scour: 1.75 ft

Scour Hole Depth from NCHRP Method: -0.19 ft

Right Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 88.72 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 10.84 cfs

Unit Discharge in the Constricted Area (q2): 8.69 cfs/ft

D50: 20.421600 mm

Upstream Flow Depth: 1.99 ft

Flow Depth Prior to Scour: 1.94 ft

Result Parameters

q2/q1: 0.80

Average Velocity Upstream: 5.44 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 5.09 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.75 ft

Maximum Flow Depth including Abutment Scour: 1.75 ft

Scour Hole Depth from NCHRP Method: -0.19 ft

Hydraulic Analysis Report

Project Data

Project Title:

Designer:

Project Date: Friday, October 14, 2022

Project Units: U.S. Customary Units

Notes:

Bridge Scour Analysis:992008 500 yr Bridge Scour Analysis

Notes:

Scenario: 500yr_Proposed-6 (SRH-2D)

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Applied Contraction Scour Depth 0.40 ft

Contraction & Long Term Scour is applied method due to greater scour.

Pressure Scour Depth 0.40 ft

Clear Water Contraction Scour Depth 0.40 ft

Live Bed Contraction Scour Depth 0.71 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.14 ft

Total Scour at Abutment 0.00 ft

Right Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.14 ft

Total Scour at Abutment 0.00 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 2.06 ft

D50: 20.421600 mm

Average Velocity Upstream: 5.56 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 5.12 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0335 ft/ft

Flow in Contracted Section: 133.10 cfs

Flow Upstream that is Transporting Sediment: 78.66 cfs

Width in Contracted Section: 13.93 ft

Width Upstream that is Transporting Sediment: 6.86 ft

Depth Prior to Scour in Contracted Section: 1.35 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 25.527000 mm

Average Depth in Contracted Section after Scour: 1.75 ft

Scour Depth: 0.40 ft

Results of Live Bed Method

Shear Velocity: 1.49 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 2.06 ft

Scour Depth for Live Bed: 0.71 ft

Shear Applied to Bed by Live-Bed Scour: 0.3637 lb/ft^2

Shear Required for Movement of D50 Particle: 0.2681 lb/ft^2

Recommendations

Recommended Scour Depth: 0.40 ft

Left Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.80 ft

D50: 0.000000 mm

Average Velocity Upstream: 3.22 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0335 ft/ft

Flow in Contracted Section: 5.57 cfs

Flow Upstream that is Transporting Sediment: 19.40 cfs

Width in Contracted Section: 2.56 ft

Width Upstream that is Transporting Sediment: 7.50 ft

Depth Prior to Scour in Contracted Section: 0.53 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Right Bank Contraction Scour
Computation Type: Clear-Water or Live-Bed Scour

Input Parameters
Average Depth Upstream of Contraction: 0.55 ft

D50: 0.000000 mm

Average Velocity Upstream: 2.50 ft/s

Results of Scour Condition
Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0335 ft/ft

Flow in Contracted Section: 12.45 cfs

Flow Upstream that is Transporting Sediment: 48.92 cfs

Width in Contracted Section: 2.52 ft

Width Upstream that is Transporting Sediment: 35.70 ft

Depth Prior to Scour in Contracted Section: 1.22 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Left Abutment Details

Abutment Scour
Computation Type: NCHRP

Input Parameters

NCHRP Method
Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 91.27 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 11.46 cfs

Unit Discharge in the Constricted Area (q2): 9.55 cfs/ft

D50: 20.421600 mm

Upstream Flow Depth: 2.06 ft

Flow Depth Prior to Scour: 2.03 ft

Result Parameters

q2/q1: 0.83

Average Velocity Upstream: 5.56 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 5.12 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.89 ft

Maximum Flow Depth including Abutment Scour: 1.89 ft

Scour Hole Depth from NCHRP Method: -0.14 ft

Right Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 88.73 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 11.46 cfs

Unit Discharge in the Constricted Area (q2): 9.55 cfs/ft

D50: 20.421600 mm

Upstream Flow Depth: 2.06 ft

Flow Depth Prior to Scour: 2.03 ft

Result Parameters

q2/q1: 0.83

Average Velocity Upstream: 5.56 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 5.12 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.89 ft

Maximum Flow Depth including Abutment Scour: 1.89 ft

Scour Hole Depth from NCHRP Method: -0.14 ft

Appendix L: Floodplain Analysis

(FHD only)